Biological changes in Celtic Sea and southwest of Ireland herring, based on a long-term data archival project

A thesis presented to Trinity College Dublin
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By

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Declaration

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Deirdre Lynch

Summary

The herring fishery in the Celtic Sea and Division VIIj has been commercially important for many years. The Marine Institute has been collecting biological data for this herring stock since 1959. This stock is assessed by ICES annually. However, this is the first study of long term biological trends.

The biological data consists of total length, weight, sex, maturity and age of the commercial catches. This study looks at mean length and mean weight at age, growth rate, condition factor and maturity ogives from 1959 to 2007. Environmental factors that may explain the biological trends are also investigated. These data consist of sea surface temperature (SST) for the Celtic Sea and the Irish Sea from 1970 to 2004, North Atlantic Oscillation (NAO) indices from 1958 to 2001 and *Calanus* spp. abundance for the Celtic Sea and Division VIIj from 1958 to 2007. In addition, data from the ICES stock assessment is consulted and this consists of spawning stock biomass (SSB), fishing mortality (F) and recruitment (R) from 1958 to 2008.

The results show that mean length and mean weight at age peaked in the 1970s and declined thereafter. It was found that the condition factor over time declined. The results also illustrate that the growth rates were faster in the 1960s and 1970s than in the 1980s and 1990s. It can be seen that maturation for 1 winter ring increased in the early 1970s and has remained at a high level since then.

This study looks at possible explanations for the biological trends and found that it was unlikely to be due to fishing mortality or density dependence. There have been

changes in the proportions of autumn and winter spawners in this area over time but it is unlikely that this influenced the trends. Evidence suggests that the changes in the biological data over time may be influenced by environmental factors. NAO shows a significant negative correlation with growth rate in length. There is evidence to suggest that increased SST in the Irish Sea and Celtic Sea is associated with reduced size/weight at age and condition. *Calanus* abundance shows some positive correlations with mean length and mean weight and is a favourable influence on herring growth.

These changes in the biology of the stock have implications for its future management. Declining growth results in more individual fish per tonne of landings which exerts a greater fishing mortality than in the past. This study has allowed for a better understanding of the biology of the stock. Biological data has been routinely collected for other herring stocks around Ireland and similar studies should be performed on these herring stocks in the future.

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1. INTRODUCTION

Herring is an important species in the Celtic Sea ecosystem and it is an important species for commercial fishing. Management of this fishery within the ecosystem requires a large body of information and it is the purpose of this study to improve the information available. The existing studies available are described in the sections below. The assessment of herring in this area is based on comprehensive biological data and this study provides an in-depth analysis of these data. Changes in growth, maturity and fecundity need to be considered when assessing and managing a stock. Changes over time in these parameters could alter the productivity of the stock and its response to fishing. It is important to consider environmental drivers for these changes. This is particularly important as the ecosystem approach to fishery management is applied.

1.1 Taxonomy

Atlantic herring *Clupea harengus harengus* Linnaeus, 1758, is a member of the Clupeidae family of teleost fishes. These are a group of small to moderately sized fishes with no spiny finrays, a single dorsal fin, and no adipose fin (Whitehead, 1984). Atlantic herring is distinguished by a keel of scutes along the belly. They have a projecting lower jaw and the gill cover does not have a radiating bony striae. The pelvic fin has usually 9 finrays with its base below or just behind the dorsal fin origin. The back is dark blue in colour and the flanks are silvery (Whitehead, 1984). Atlantic herring (hereafter referred to simply as herring) is distinguished from the similar species: 1. sprat *Sprattus sprattus*, which has the pelvic fin origin under or before the dorsal fin origin and 30 – 41 gillrakers, 2. allis *Alosa alosa* and twaite *Alosa falax* shads, which have an upper jaw with a median notch, 3. pilchard *Sardina pilchardus*, which has gill covers with radiating bony striae (Whitehead, 1984).

1.2 The environment of the Celtic Sea and Southwest Ireland

1.2.1 Oceanography

The Celtic Sea is a shallow embayment of the eastern North Atlantic (Cooper, 1967) and is located to the south of Ireland. It is bounded to the east by Saint George's Channel, the Bristol Channel and the English Channel and extends south towards the Bay of Biscay. It is limited to the west by the slope of the Porcupine Seabight and Goban Spur (Anon, 2008b). The area of the Celtic sea extends from 48° and 51.5° N and 5° and 12° W and to 1000 m at the edge of the continental slope.

The southwestern Celtic Sea contains a series of long parallel banks and troughs of unknown geological origin. Large areas have an almost flat topography from which a number of banks arise (Admiralty, 1957). In the northeasterly part, there is much rough ground which is in part deposited from moraine of the Irish Sea and Welsh glaciations and in part due to outcrops of Variscan granite (Curry *et al*, 1962).

The climate is windy, cloudy, damp and rainy. Rainfall and storminess decreases from west to east. Gales may occur in any month but are ten times more frequent at midwinter than in midsummer. They blow mostly from southwest or west, occasionally from north and rarely from south or east. Overall the weather is highly variable (Cooper, 1967; Meteorological Office, 1940).

Thermal stratification and tidal mixing generate the Irish costal current which runs westwards in the Celtic Sea and northwards along the west coast of Ireland (Fernand *et al*., 2006). In the Irish Sea, an inshore coastal current carries water from the Celtic Sea and St. Georges Channel northwards through the North Channel, mixing with water from the outer Firth of Clyde. On the shelf, tidal mixing and thermal/saline fronts occur. For example in the English Channel there is the Ushant Front and in the southern entrance to the Irish Sea there is the Celtic Sea front (Anon, 2008b). Another oceanographic front in this area is the Irish Shelf Front that occurs to the south and west of Ireland (at ca. 11°W) and exists all year-round. This front marks the boundary between waters of the shelf (often mixed vertically by the tide) and offshore North Atlantic waters. The turbulence caused by the front introduces nutrients from deeper water to the surface where they promote the growth of phytoplankton, especially diatoms in spring, but also dinoflagellates especially where there is pronounced stratification. These are in turn fed on by cohorts of zooplankton and associated with these are aggregations of fish (Reid *et al.*, 2003). Oceanographic conditions in the Celtic Sea and Division can be seen in Figure 1.2.1

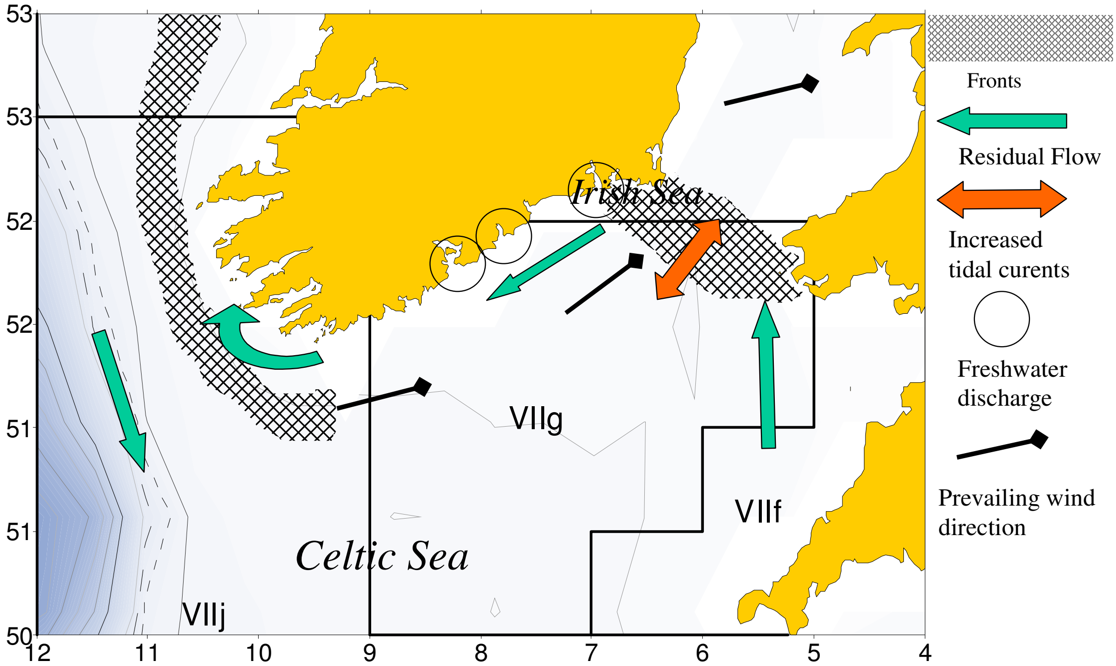


Figure 1.2.1 Schematic presentation of prevailing oceanographic conditions in the Celtic sea and VIIj (Anon, 2005c, SGRESP).

1.2.2 Temperature

Temperatures in the Celtic Sea have been increasing over the last number of decades and there are indications that salinity is also increasing (Anon, 2008b).

1.2.3 North Atlantic Oscillation

The North Atlantic Oscillation index (NAO) is a measure of the difference in normalized sea level pressure between Iceland and the subtropical eastern North Atlantic. The NAO is thought to have an influence on the climate of the Celtic Sea (Anon, 2008b). When the winter NAO index is positive, it coincides with colder and drier conditions over the western North Atlantic and warmer, wetter conditions in the eastern North Atlantic. During a negative NAO, a weakening of the Icelandic low and Azores high decreases the pressure gradient across the North Atlantic and this tends to reverse the effect. The winter NAO experienced a strong negative phase in the 1960s, but became more positive in the 1980s and early 1990s. It remained mainly negative from 1996 to 2004.

1.2.4 <u>River discharge</u>

Several rivers discharge fresh water into the Celtic sea ecoregion and influence the circulation patterns; these are notably the River Loire, the Severn, the Shannon and the Irish rivers Lee and Blackwater in the Celtic Sea (Figure 1.2.4) (Anon, 2008b).

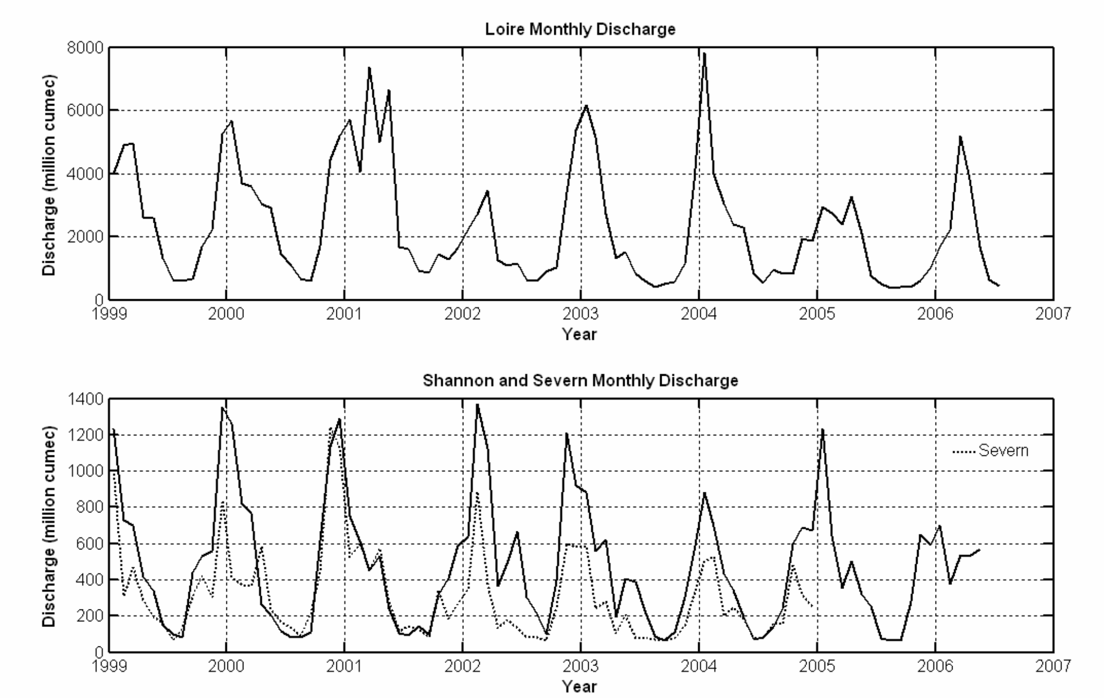


Figure 1.2.4 Discharges from rivers affecting the Celtic Sea Shelf: the river Loire (upper panel) and rivers Shannon and Severn (lower panel). Note different scales on Y-axes (Anon 2008b).

1.2.5 <u>Productivity in the Celtic Sea</u>

In this area productivity is reasonably strong on the shelf but drops rapidly west of the shelf break. Based on Continuous Plankton Recorder (CPR) greenness records for this area, the spring bloom occurs around April and collapses by October, although in recent years it has continued into December. The CPR survey is a monitoring program using ships of convenience to collect under way plankton samples. CPR data also suggest that there has been a steady increase in phytoplankton colour index across the whole area over at least the past 20 years. Phytoplankton productivity and taxonomic composition in the Celtic Sea has been shown to depend on water column structure (Anon, 2008b). Diatoms dominate well mixed areas with high nutrient content and display high rates of productivity, while dinoflagellates and microflagellates are found in stratified waters exhibiting lower rates of productivity (Raine *et al.*, 2002). Certain oceanographic conditions can lead to the formation of toxic algal blooms around Irish coasts, with the highest occurrence noted along the southwest of Ireland. Large harmful algal blooms recorded in 2005 were associated with the dinoflagellate *Karenia mikimotoi* and caused mortalities to benthic and pelagic marine organisms at a scale that has not previously been observed (Silke *et al.*, 2005).

1.2.6 <u>*Calanus* abundance</u>

The overall abundance of zooplankton in this region has declined in recent years. The Celtic Sea shows a substantial drop in *Calanus* abundance and it is now below the long-term mean (Anon, 2008b).

1.2.7 Fish community

The Celtic Sea groundfish community consists of over a hundred species and the most abundant 25 comprise 99% of the total estimated biomass and around 93% of total estimated numbers (Trenkel and Rochet, 2003). Population and community analyses have shown that fishing has impacted a number of commercial species. This is primarily because individuals of too small a size for commercial purposes have been caught and discarded in the past (Trenkel and Rochet, 2003; Rochet *et al.*, 2002). The size structure of the fish community has changed significantly over time, and a decrease in the relative abundance of larger fish has been accompanied by an increase in smaller fish (Blanchard *et al.*, 2005; Trenkel *et al.*, 2004).

Temporal analyses of the effects of fishing and climate variation suggest that fishing has had a stronger effect on size-structure than that affected by changes in temperature. A marked decline in mean trophic level of the fish community over time has been documented (Pinnegar *et al.*, 2003), resulting in a reduction in the abundance of large piscivorous fishes such as cod and hake, and an increase in smaller pelagic species which feed at a lower trophic level. (Anon, 2008b)

For the Celtic and Irish Seas, two sources of fish stomach data have recently been collated and these are described by Pinnegar *et al.* (2003). The main predator species in the Celtic Sea (hake, megrim, monkfish, whiting, cod, saithe) are generalist feeders which exhibit size-dependent, temporal, and spatial prey switching behaviour (Pinnegar *et al.*, 2003; Trenkel *et al.*, 2005).

Overall, greater prey densities in the environment coincide with greater occurrences of prey species in predator stomachs (Trenkel *et al.*, 2005). Blue whiting was found more often in predator stomachs over the shelf edge during the summer months while mackerel and *Triopterus* spp were relatively more prevalent in stomachs sampled on the continental shelf during the winter. No major studies of forage fish have been conducted in the ecoregion. Sand eel *Ammodytes* spp., sprat, and Norway pout *Trisopterus esmarki* are known to be present, but their role and importance in the ecosystem remains unclear.

Fish taken from the shelf edge areas of the Celtic Sea tend overall to be less planktivorous and from a higher trophic level than those in the North and Baltic Seas (Heath, 2005). The secondary production required per unit of landed fish from the southern part of the Celtic Seas is suggested to be twice that for North Sea fish. In the Celtic Seas benthos production has been suggested to be a bottom-up driver for fisheries production, which seems to be independent of variability in plankton production. As this situation is very different to the situation in the North Sea, climate change and fishing pressures might be expected to influence these regional fisheries in very different ways (Anon, 2008b)

Basking sharks (*Cetorhinus maximus*) are seen throughout the Celtic Sea from April to October. Blue Sharks (*Prionace glauca*) are found in the summer and are subject to a variety of fisheries. They are taken in both recreational and directed (longlines and gillnets) fisheries and are also taken as bycatch in the offshore tuna fisheries. Porbeagle (*Lamna nasus*) and tope (*Galeorhinus galeus*) are also targeted in both recreational and commercial fishing (Anon, 2008b).

Six species of cetaceans are regularly observed in this area (Reid *et al*., 2003). Species such as minke whale (*Balaenoptera acutorostrata)*, bottlenosed dolphin (*Tursiops truncates*)*,* common dolphin (*Delphinus delphis*), white-beaked dolphin and white-sided dolphin (*Lagenorhynchus albirostris* and *L. acutus*) have been observed throughout the region. Harbour porpoise (*Phocoena phocoena*) is the smallest, but by far the most numerous of the cetaceans found in the Celtic Seas ecoregion (Hammond *et al*., 2002; Wall *et al*., 2004). Grey seals (*Halichoerus grypus*) are common in many parts of the area, and 5000 – 7000 are thought to exist in the Irish and Celtic Seas (Kiely *et al*., 2000). Small numbers of Common seals (*Phoca vitulina*) are seen in the area.

Herring is a key component in the Celtic Sea ecosystem. It is an important consumer of zooplankton (Section 1.3.3). However it is also an important prey item for many predators. It is known that herring are preyed upon by grey seals (Harris, 2007), baleen whales (Johnston et al. 2005), and various fish species – saithe, cod, hake, megrim and whiting (Pinnegar et al. 2003; Trenkel et al. 2005). Therefore herring acts as a link between the primary consumers and higher trophic layers. Herring is not the only species performing this role however. For instance, sprat is a competitor of herring for the same prey (Mollman et al. 2004).

1.3 General biology of herring

1.3.1 Distribution and migration

Herring are distributed in the Atlantic from the Bay of Biscay in the extreme south to Greenland, Iceland, Spitsbergen and Novaya Zemlaya. They are also found in the south-eastern part of Barents Sea, and in the western North Atlantic, from South Carolina to Greenland. In the White Sea a sub species *C.h. marisalbi* is found, in part of the Kara Sea the sub species *C. h. suworowi* is found while in the Baltic Sea the sub species *C. h. membras* is found (Whitehead, 1984). Rass and Wheeler (1991) elevated Pacific herring to the status of a separate species, *Clupea pallassi.* Previously, Pacific herring was considered to form a subspecies called *C. harengus. Pallasi* (Whitehead, 1984). Therefore White Sea herring is now considered a sub-species, *C. palassi marisalbi.*

Herring undergo triangular migrations from spawning grounds, to feeding grounds to wintering grounds. This has been well documented for Norwegian Spring Spawning herring (Slotte, 1998). The migrations of herring around Ireland are less clear, but it is known that they have defined spawning, feeding and wintering grounds. Journeys of 500 or 600 kilometres may be made each season (Molloy, 2006)

According to the time of the year in which they spawn, herring are characterised as spring or autumn spawners (Wheeler, 1969). However as pointed out by Whitehead (1984), herring spawning occurs in every month of the year with each stock or stock component having a different spawning time in spring, summer, autumn and winter. Different stocks also have different spawning places.

Wheeler (1969) states that the distribution of important food items such as *Calanus* spp. and *Temora* spp. have a bearing on the presence and migration of herring.

1.3.2 Population Structure

Heincke (1898) was the first to divide herring into stocks. According to Wheeler (1969) herring can be divided into a number of more or less distinct populations or stocks, based on morphological and biological characteristics. Iles and Sinclair (1982) considered that herring populations were more or less discrete from other populations over time. The known herring stocks are listed in Table 1.3.2 .and are based on Hay *et al* (2001b).

Table 1.3.2. The known herring stocks, based on Hay *et al* (2001b).

Northeast Atlantic Stocks	**Northwest Atlantic Stocks**	**Northeast Pacific Stocks**
Icelandic Summer Spawners	Western Newfoundland (Spring & Autumn Spawners)	British Columbia
Norwegian Spring Spawners	East and Southeast Newfoundland (Spring & Autumn Spawners)?	Gulf of Alaska
Icelandic Spring Spawners	Gulf of St. Lawrence (Spring & Autumn Spawners)	Bering Sea
West of Scotland (VIa)	Georges Bank (Spring & Autumn Spawners)	Western Bering Sea
West of Ireland & Porcupine Bank	Gulf of Maine	California
Celtic Sea & VIIj	Scotia-Fundy	
Irish Sea		
Clyde	**Northwest Pacific Stocks**	**Arctic Stocks**
VIIe & VIIf	Korf - Karagin	White Sea
Thames Estuary	Gizhiga - Kamchatka	Chesa - Pechora
Downs	Otkhotsk Sea	Beaufort Sea
North Sea Autumn Spawners	Dekastri	Chuchki Sea
Western Baltic Spring Spawners	Peter The Great Bay	Barents and Kara Sea
Local Coastal Norwegian Stocks	Yellow Sea	Laptev and East Siberian Sea
Central Baltic Sea	Hokkaido - Sakhalin	Greenland Sea
Southern Bothnian Sea		
Northern Bothnian Sea		

In the northeast Atlantic, 16 management units are considered by the International Council for the Exploration of the Sea (ICES). The areas in Table 1.3.2 also constitute management units, and there may be reasons to assume that stock identification is more complicated than suggested. A series of projects have recently been completed that investigate the stock structure of NE Atlantic herring (Hatfield *et al*, 2007 and references therein).

Considerable research has been conducted on herring stocks for many years and there are many different perceptions of stock identity. This research includes morphometric analyses (Hatfield *et al*, 2007), meristic counts (Hulme, 1995), parasitology (Hatfield *et al*, 2007), genetics (King, 1983), otolith microstructure (Moksness and Fossum, 1991; Brophy and Danilowicz, 2002), microchemistry (Hatfield *et al*, 2007) and otolith shape analysis (Burke *et al*, 2008a; 2008b). Hulme (1995) outlines the problems using meristic counts. This led to the discontinuation of the method of counting vertebrae for stock separation. Smith and Jamieson (1986) claim that a herring stock is a transient sub-division and has no taxanomic or evolutionary status. McQuinn (1997) suggests that the population structure and dynamics are well described within the metapopulation concept. That is to say, the local stock is maintained through behavioural isolation meaning repeat rather than natal homing to spawning grounds. Local population persistence is ensured by the social transmission of migration patterns and spawning areas from adults to recruiting individuals.

1.3.3 <u>Food</u>

Food consumed by herring varies considerably, with time and place. In the young stages herring is a plankton feeder, while later it feeds on larger animals. Feeding commences when the larval yolk sac is still present (~10 mm Total length (TL)). At this stage, food is composed of diatoms and flagellates, followed by eggs and nauplii of harpacticoid copepods and *Pseudocalanus.* After the absorption of the yolk sac, smaller copedods such as *Pseudocalanus, Temora* and *Microcalanus* predominate. Herring in their first year mainly eat crustacea, the *Calanus* copepods, the larvae of acorn barnacles and Mysid shrimps, eggs and larvae of decapods and amphipods.

They also eat juvenile fish, for example sandeels *Amodytes.* Adult herring still continue to eat *Calanus finmarchicus* and *Temora longicornis*. Crustaceans such as Hyperid amphipods (e.g. *euphausids* and *Hyperia galba*) and euphausiids are also eaten, together with gobies, whiting, flatfish, and herring. Among the other invertebrates herring also eat arrow worms, Pterapods and Ctenophores (Mollman et al., 2004; Segers et al. 2007; Wheeler, 1969).

Wheeler (1969) points out that herring deliberately select certain plankton and do not feed randomly. Iles, (1984) states that in the North Sea stock, feeding begins in March, peaks in May and declines to a low level by August. This author goes on to conclude that one third of the seasons growth has occurred by May and the remaining growth is completed by the end of July. It is thought that Atlantic herring do not feed during the winter and are sustained by stored lipids over this period. (Bradford, 1993).

1.3.4 Age and growth

In teleost fish, the most common method of age estimation is using otoliths. These are small bones in the middle ear of the fish that have growth increments present (Panfili *et al.*, 2002).

For most fishes the formation of daily growth rings starts at the end of the yolk sac stage or at the time that the eyes become pigmented. The exact time of formation of the first daily growth increment varies among species. The width of daily increments can be influenced by a number of factors such as food uptake, temperature and other environmental conditions. The distance between increments expresses the daily growth of the individual, while the number indicates its age in days (Secor *et al.* 1995, Fossum *et al.* 2000, Panfili *et al.*, 2002).

An important aspect of fish age reading is the analysis of accuracy and precision. Accuracy is the study of whether the estimate of age is true and precision is a measure of the reproducibility of the estimate (Cailliet, 1990)

Herring are aged using either otoliths or scales, depending on the stock in question (Hay *et al*, 2001b). The maximum age for herring stocks is reported by these authors to range from 12 years (British Columbia) to 20 years (Bering Sea, West Newfoundland) and 22 years (Norwegian Spring Spawning herring) (Beverton *et al*., 2004).

<u>Maturation</u>

In Norwegian Spring Spawning herring, year classes that mature later than normal attained a greater maximum age than those maturing earlier. The herring were found to spawn 8 times before dying (Beverton *et al*, 2004). Toresen (1990) found that weaker year classes in Norwegian Spring Spawners had a stronger growth rate before maturity and a weaker growth rate after maturity. Density dependant change in maturity was found for Norwegian spring spawning stock and when SSB was low the fish matured at an earlier age (Engelhard and Heino, 2004).

Maturation in herring is usually described according to a maturity scale (Landry and McQuinn, 1998, Anon, 2003) and this is presented in Appendix II.

1.3.5 Reproduction and fecundity

Hay *et al* (2001b) presents age at maturity for many herring stocks. Stocks that mature early/young include Baltic Sea herring and North Sea herring. These herring reach maturity from age 2-3 years. Stocks that mature late (older) include Norwegian spring spawners and Gulf of St. Laurence spring and autumn spawners. These stocks reach maturity at age 5.

Beverton (1963) showed that the length of first maturity was proportional to maximum fish length. Maturation is governed by the pituitary gland (Iles, 1964). It has proved difficult to determine how long, within a year, the maturation process takes. In the North Sea, herring progressed from the end of stage 1 (virgin) to the beginning of stage 5 (ripe) in 86 days for males and 112 for females. In the case of Manx herring, the older fish mature earlier but hold at stage 5 for longer (Iles, 1964). Importantly, differences in spawning time can be attributed to the duration of stage 5. Spring spawners generally have a long stage 5 duration, develop less gonad and contain lower levels of somatic lipids and proteins at spawning time, than autumn spawners (Bradford, 1993).

Bridger (1961) concluded that younger fish spawned on the Downs grounds early in the spawning season and that older fish spawned later. Slotte (2001) found two waves of spawners returning to the Norwegian grounds, the repeat spawners arrived first, followed by the recruit spawners that have a delayed onset of maturation.

Fecundity and atresia

In an early study of fecundity, Farran (1938) found that, for a given length, spring spawners had lower fecundity than autumn spawners. He also found that spring spawners had bigger eggs. Baxter (1959) found the same feature and reported that there were greater differences with fecundity at age. However Almatar and Bailey (1989) did not find any difference with fecundity at age in the Firth of Clyde and Northern North Sea stock. Bradford and Stephenson (1992) found in Northwest Atlantic herring that egg sizes in autumn and spring spawners were similar but that summer spawners had different fecundity.

There is debate in scientific literature about changes in fecundity between years and possible reasons for these changes. Fecundity varies within stock areas (Bridger, 1961). Zijlstra (1973) concluded that there were two separate stocks in the North Sea but that the difference in fecundity could not be attributed to just temperature or food as both stocks mix outside spawning time.

In the Northwest Atlantic, Winters *et al* (1993) noted that annual variations in fecundity could be substantial. These authors found that prior to spawning, sea temperatures had the greatest effect on fecundity. Further evidence of this effect was found by Tanisichuk and Ware (1987) who stated that colder winter temperatures could lead to the re-absorption of eggs (atresia) and reduced fecundity.

Higher atresia was found to be due to reduced feeding, leading to much lower realised fecundity (Ma *et al*, 1998). However these authors found no relationship between reduced feeding, oocyte size and potential fecundity. This supports earlier work by Zijlstra (1973) who could not find any relationship between fecundity and condition.

Almatar and Bailey (1989) found no evidence that low stock size is associated with changes in fecundity. In contrast, Winters *et al* (1993) suggests that fecundity is higher when stock size is lower.

1.3.6 <u>Spawning and early development</u>

Herring are benthic spawners and deposit their eggs on the sea bed usually on gravel or course sediments. However Pacific and Baltic herring spawn on sub-tidal vegetation (Geffen, 2009). The larvae hatch with a yolk sac and adopt a pelagic mode of life (Wheeler, 1969).

Wheeler (1969) states that herring spawn in waters from depths of 15m to deeper waters of 200m on the edges of ocean banks. Depths of as shallow as 0-5 m off Greenland and as deep as 200m in autumn spawning herrings of the North Sea have been reported (Hay *et al*, 2001b). The eggs are heavier than seawater and adhere to the substrate (Wheeler, 1969). They form a thin layer over the substrate at the spawning site. The eggs are 0.35-1.5 mm in diameter, but size depends on parent fish and stock or local race (Farran, 1938).

Parrish *et al* (1959) found in their study of Clyde herring that the eggs were located in an area of small stones and gravel and none were found in areas of large stones, boulders or rock. The eggs were distributed in an almost continuous carpet with a thickness of 4-8 eggs over most of the patch and a thickness of 1–2 eggs at the edges of the patch.

De Groot (1980) states that stones, gravel, shingle, pebbles, shells and seaweed are the preferred substrate of herring in the North Sea. Elsewhere the preferred substrates are gravel bottoms for Atlantic herring and vegetative substrate for Pacific herring and spring spawning Atlantic herring (Hay *et al*, 2001b). Breslin (1998) states the spawning substrates around Ireland are gravel, stones, broken mussel shell and flat rock. The temperature of the water at spawning time varies from 4°C in Gulf of Alaska and the Bering Sea to 18°C in the Baltic Sea (Hay *et al*, 2001b).

When referring to spawning locations the following terminology was proposed by Breslin (1998; Molloy, 2006).

- A <u>spawning bed</u> is the area over which the eggs are deposited
- A <u>spawning ground</u> consists of one or more spawning beds located in a small area.
- A <u>spawning area</u> is comprised of a number of spawning grounds in a larger area

Spawning grounds in Irish waters are typically located in high energy environments such as the mouth of large rivers and areas where the tidal currents are strong. Herring shoals return to the same spawning grounds each year (Molloy, 2006).

Fertilisation

Spawning takes place over a short period, normally a few days and the fertilized eggs remain on the bottom for a period of 2-3 weeks, depending on the water temperature. They then hatch into larvae and the size of the egg determines the size of the larvae. Larger eggs have a greater chance of survival but this must be balanced against environmental conditions and the inverse relationship between fecundity and egg size. This is because larger eggs can be expected to have a greater chance of survival (Blaxter and Hunter, 1982).

Males fertilise the female eggs on the spawning beds. Sperm were found to remain motile for up to 5 minutes and motility was longer in the presence of eggs (Geffen, 1999).

The extent to which herring return to the same spawning ground is subject to debate. De Groot (1980) described attempts by herring to return to the Zuiderzee area where spawning used to take place even after the area had been closed off. It is also unclear if herring remain faithful to their own spawning ground. Brophy *et al* (2006) propose that spawning season switching may occur due to environmental influences on gonad development in adults. Aneer, (1985) suggested that large and sudden changes in the pre spawning environment may lead to spawning season switching.

Another subject of debate is the degree to which herring skip spawning. Engelhard and Heino (2004) suggest that Norwegian spring spawners do not reproduce every year. However Kennedy *et al* (2008) found that skip spawning occurs to a very limited extent. These authors suggests that there could be an over estimation of mature adults because the young “failed spawners” could be classified as mature.

Early Life

After hatching, larvae are pelagic, and are distributed often in shallow waters (Wheeler, 1969). Herring larvae tend to be distributed in the upper two thirds of the water column (Heath *et al*, 1988). Growth of larvae is thought to be related to inherited genetic influences (Bang *et al*, 2006) and/or hydrographic conditions and plankton abundance (Heath *et al*, 1997). Temperature at incubation in the range of 3.5-17°C, had little effect on the conversion of egg reserves to the body (Overnell, 1997). These temperatures could be considered the temperate range tolerable for larval herring. Juvenile herring tend to remain close inshore, in shallow waters for the first two years of their lives, in nursery areas (Molloy, 2006).

1.4 Herring in the Celtic Sea and Division VIIj

1.4.1 Distribution, Migration and Stock Identity

International Council for the Exploration of the Sea (ICES) is an intergovernmental body that manages the fish stocks in the North Atlantic Ocean and adjacent seas. The herring management unit to the south of Ireland in the Celtic Sea and in Division VIIj comprise both autumn and winter spawning stock components. These areas are shown in Figure 1.4.1. Today they are assessed as one stock. Prior to 1982, herring in both these areas were assessed and managed separately. In 1977 the fishery in the Celtic Sea was closed because the stock had collapsed. In 1982 the areas were combined by ICES for assessment purposes and subsequently have been managed by the EU as a combined stock. The decision to amalgamate the two areas was supported by biological data that showed similarities in age profiles between the two areas (Anon, 1982). In addition, larvae from the spawning grounds in the western part of the Celtic Sea were shown to be transported into VIIj (Molloy, 1968; Anon, 1982).

An ICES study group examined stock boundaries in 1994 and recommended that the boundary line latitude 52°30'N that separated the herring stocks in the Celtic Sea and Division VIIj (SW Ireland) from that in Division VIaS and VIIb (NW Ireland) should be moved southwards to latitude 52°00'N. This recommendation was based on biological data available at the time (Anon, 1994a). However, a recent study (Hatfield *et al.* 2007) examined the stock identity of stocks around Ireland and concluded that the Celtic Sea stock area should remain unchanged. Brophy *et al* (2006) investigated spawning season fidelity in sympatric populations of herring in the Celtic and Irish Sea. The study suggested that within the Irish Sea there is a large degree of mixing juveniles from the Irish Sea and the Celtic Sea. However the study suggests that there is very little mixing of the adult populations. This migration has also been verified through herring tagging programmes conducted in the early 1990s by Molloy *et al,* (1993), the results of which are shown in Figure 1.4.1.

Age distribution of the stock suggests that recruitment in the Celtic Sea occurs first in the eastern area and follows a westward movement. After spawning herring move to the feeding grounds offshore. In Division VIIj herring congregate for spawning in autumn but little is known about where they reside in winter (Anon, 1994a). A schematic representation of the movements and migrations is presented in Figure 1.4.2. The larval drift from the spawning and nursery grounds is shown with larvae from Division VIIaS moving north to the Irish Sea and larvae from Division VIIg spawning/nursery grounds moving south west to Division VIIj. The juvenile migration from the Irish Sea to Celtic Sea and the migration back and forth from feeding grounds to spawning grounds can also be seen. Larvae spawned in Division VIIj are thought to be transported to Division VIIb and Galway Bay in particular (Grainger, 1979; Molloy *et al*, 1993; Anon, 1994a).

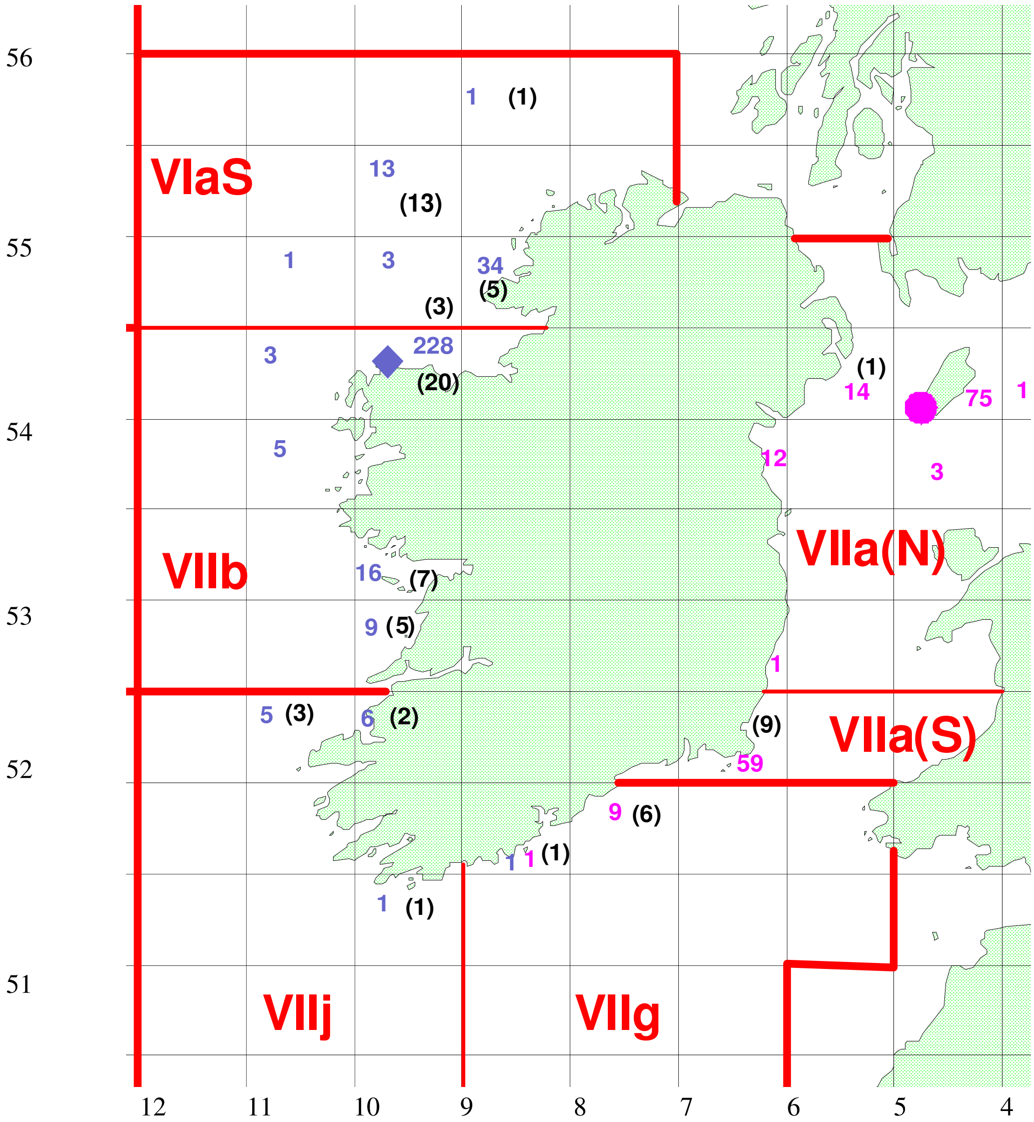


Figure 1.4.1 Results of tagging experiments conducted by Molloy *et al* (1993), redrawn by R.D.M. Nash. Large symbols indicate tagging locations and small symbols of same colour indicate the recaptures of fish tagged in each of those locations.

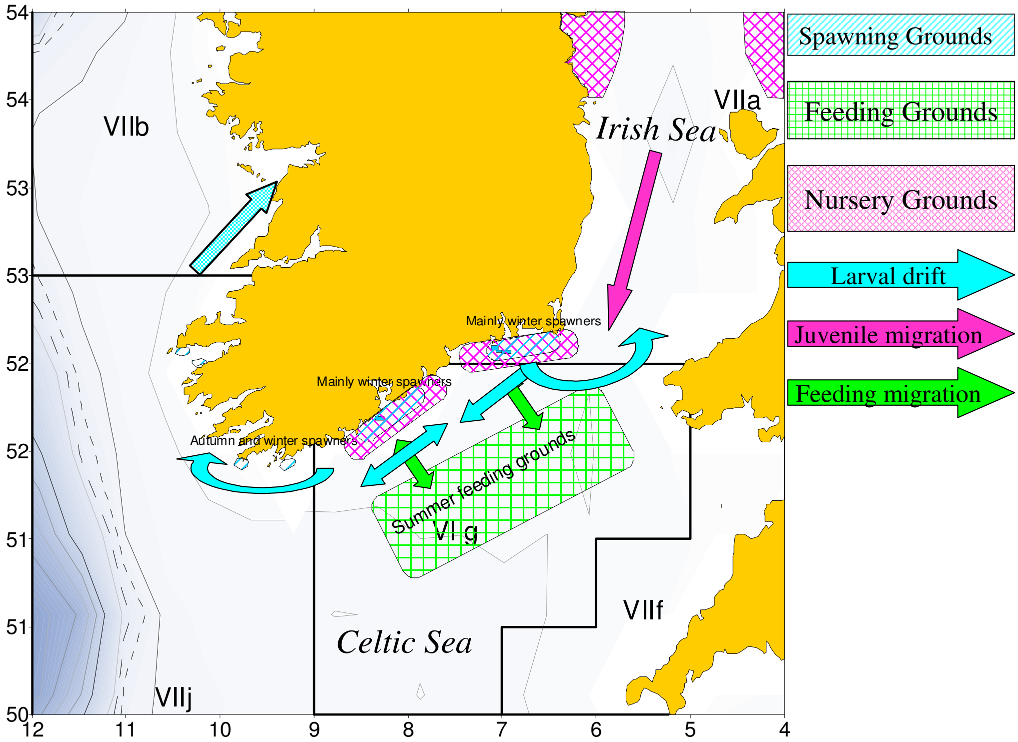


Figure 1.4.2 Schematic presentation of the life cycle of Celtic Sea and VIIj Herring (Anon, 2005c, SGRESP).

Herring larval drift occurs between the Celtic Sea and the Irish Sea. The larvae metamorphose into juveniles and remain for one or two years before returning to the Celtic Sea. Catches of herring in the Irish Sea may therefore impact on recruitment into the Celtic Sea stock (Molloy, 1989). Distinct patterns were evident in the otolith microstructure (Brophy and Danilowicz, 2002). It is thought that this is caused by environmental variations. Variations in growth rates between the two areas were found with Celtic Sea fish displaying fastest growth in the first year of life (Brophy and Danilowicz, 2002). Larval dispersal is thought to further influence maturity at age. In the Celtic Sea fast growing individuals mature in their second year (1 winter ring (wr)) while slow growing individuals spawn for the first time in their third year (2 wr). The dispersal into the Irish Sea which occurs before recruitment and the subsequent decrease in growth rates could thus determine whether juveniles are recruited to the adult population in the second or third year (Brophy and Danilowicz, 2003).

1.4.2 <u>Age and growth</u>

In Celtic Sea herring, otoliths are used to detect periods of fast and slow growth. The age of the herring is determined by counting the periods of slow growth (winter rings) that are laid down on the otolith.

A number of significant growth changes have occurred in the Celtic Sea stock. These are very evident when looking at the average length-at-age in the early 1960s compared to the average length-at-age in the 1970s and more recent years (Molloy, 2006; Anon, 2009).

1.4.3 <u>Reproduction</u>

The spawning grounds for herring in the Celtic Sea are well known and are located inshore close to the coast. These spawning grounds may contain one or more spawning beds on which herring deposit their eggs. Individual spawning beds within the spawning grounds have been mapped and consist of either gravel or flat stone (Breslin, 1998). Spawning grounds tend to be vulnerable to anthropogenic influences such as dredging and sand and gravel extraction. The main spawning grounds are displayed in Figure 1.4.3, whilst the distributions of spawning and non-spawning fish are presented in Figure 1.4.4, based on an experienced fisherman's records (Griffin pers comm). It can be seen from Figure 1.4.3 that the spawning grounds in the southwest are for autumn spawners whilst elsewhere the spawning grounds consist of both autumn and winter spawners (Molloy, 2006; Breslin, 1998)

A number of spawning grounds are located along the South coast, extending from the Saltee Islands to the Old Head of Kinsale. These grounds include Baginbun Bay, south of Dunmore East, around Capel and Ballycotton Islands and around the entrance to Cork Harbour (Molloy, 2006). The areas surrounding the Daunt Rock and old Head of Kinsale have also been recognised as spawning grounds (Breslin, 1998).

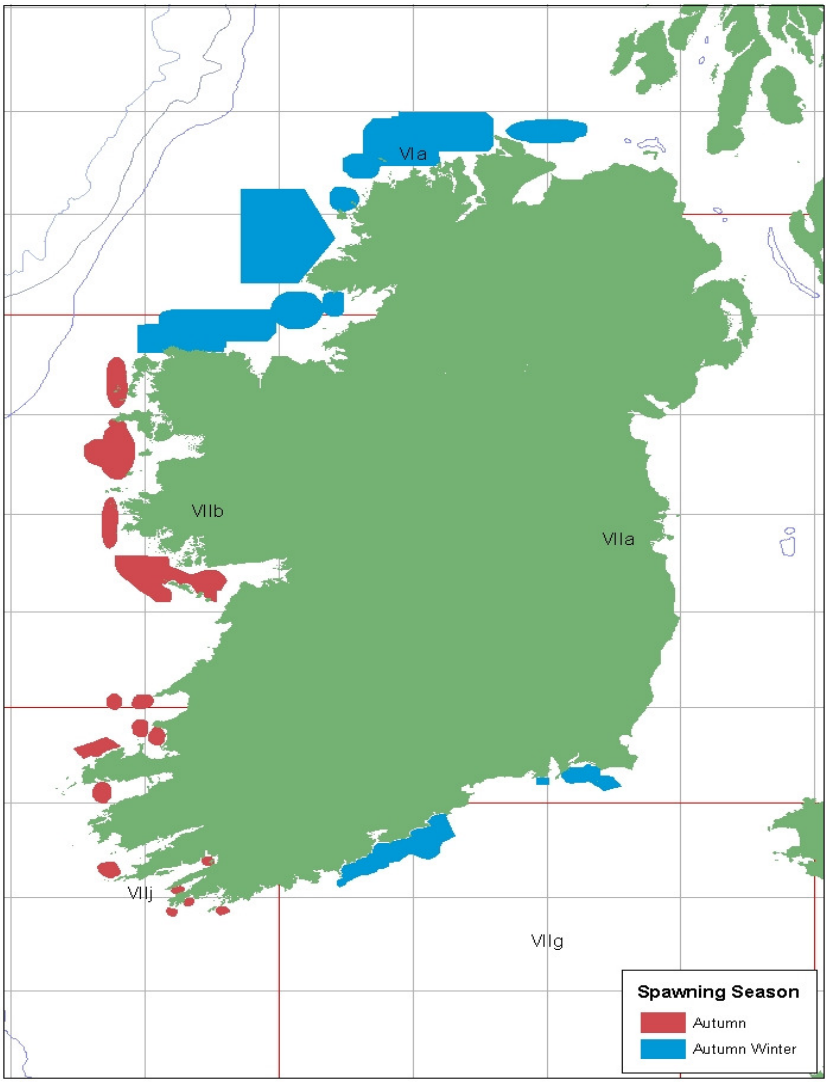


Figure 1.4.3 Location of spawning grounds of herring around the Republic of Ireland, based on fishermen's knowledge and distribution of <10mm Herring Larvae (Breslin, 1998). Note: Off northwest coast spring spawning also occurs.

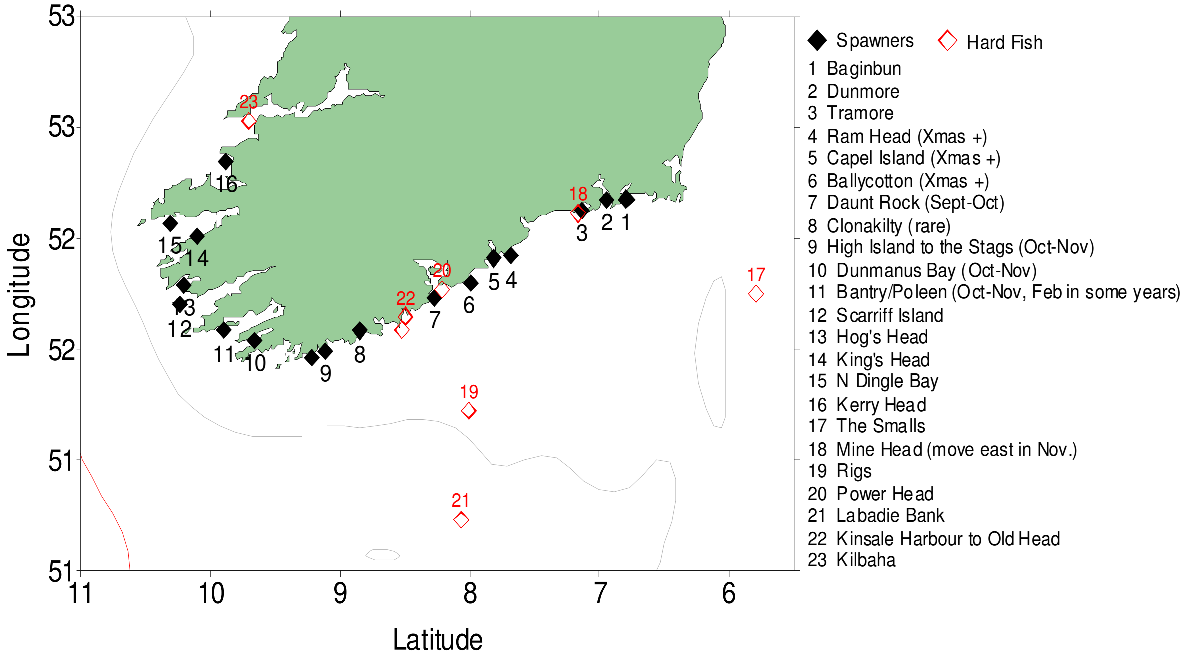


Figure 1.4.4. Location of spawning (closed symbol) and non spawning (open symbol) herring in the Celtic Sea and SW of Ireland. Hard fish denotes fish that are not in spawning condition (pre-spawning).

A study on fecundity of Celtic Sea herring, conducted in the 1920s found that the eggs produced by northwest Irish spring spawners were 25% bigger than those autumn spawners but were less numerous (Farran, 1938). Later studies of Celtic Sea herring fecundity by Molloy (1979), found that the fecundity/weight relationships were very similar to those estimated by Farran (1938). Larval studies showed that in the late 1970s the autumn spawning component was stronger than the winter spawning one.

The relationship between fecundity and length has been calculated for both spawning components of Celtic Sea herring. The regression equations shown by Molloy (1979), are as follows:

Autumn spawning component: Fecundity = 5.1173 L – 56.69 (n=53)

Winter spawning component: Fecundity = 3.485 L – 35.90 (n=37)

1.5 Fisheries for herring in the Celtic Sea and Division VIIj

1.5.1 Historical fishery development

Coastal herring fisheries off the south coast of Ireland have been in existence from at least the seventeenth century (Burd and Bracken, 1965). These fisheries have been an important source of income for many coastal communities in Ireland. There have been considerable fluctuations in herring landings since the early 1900s.

In the Celtic Sea, historically, the main fisheries were the early summer drift net fishery and the Smalls fishery which also took place in the summer. In 1933 several British vessels, mainly from Milford Haven, began to fish off the coast of Dunmore East and the winter fishery gained importance. The occurrence of the world war changed the pattern of the herring fishery further with little effort spent exploiting herring in the immediate post war years (Burd and Bracken, 1965). Landings of herring off the south west coast increased during the mid 1950s when fleets from Germany and The Netherlands began to exploit the fishery.

In 1956 Dunmore East was considered as the top herring port in Ireland with over 3,000 t landed. This was mainly sold fresh to the UK or cured (salted and barrelled) and sent to the Netherlands (Molloy, 2006). This continued until the 1960s when catches began to fall. In 1961 the Irish fishery limits changed whereby non-Irish vessels were prohibited from fishing in the inshore spawning grounds (Molloy, 1980). Consequently, continental fleets could no longer exploit herring on the Irish spawning grounds and buyers had to purchase herring from Irish vessels in order to meet requirements (Molloy, 2006).

During the period from 1950-1968 the fleet exploiting the stock changed from using mainly drift and ring nets to trawls. Further fluctuations in the landings were evident during this time with high quantities of herring landed from 1958 – 1960 and from 1966 – 1971 (Molloy, 1972). In the mid-sixties, the introduction of mid-water pair trawling led to greater efficiency in catching herring and this method is still employed today. Overall the 1960s saw an increase in landings that peaked in 1969 when 48,000t were landed.

During the 1960s the North Sea herring fisheries were becoming depleted and several countries were turning to Ireland to supply their markets. Prices also increased and additional vessels entered the fleet (Molloy, 1995). Increases in effort led to increased catches initially but this did not continue and the decline of the fishery began. A summary of the Irish fishery since 1958 is shown in Table 1.5.1.

Table 1.5.1. The basic history of the Celtic Sea and Division VIIj Irish fishery since 1958.

Time period	**1958-1977**	**1977-1983**	**1983-1997**	**1998-2004**	**2004-2009**
Type of fishery	Cured fish	Closure	Herring roe	Fillet/whole fish	Fillet/whole fish
Quality of catch data	High	Medium	Low	Medium/low	High
Source of catch data	Auction data	Auction data	Skipper logbook estimate	Skipper logbook estimate	Weighbridge landings
Discard Levels	Low	Low	High	Medium	Medium
Incentive to discard	None	None	Maturity stage	Size grade, market vs. quota	
Alloowance for water*	na	na	na	20%*	2%*

* RSW only. These vessels are more dominant in recent years.

1.5.2 Modern Fishery

In the past, fleets from the UK, Belgium, The Netherlands and Germany as well as Ireland exploited Celtic Sea herring. In recent years however this fishery has been prosecuted entirely by Ireland. The fishery is managed by the Irish "Celtic Sea Herring Management Advisory Committee", established in 2000 and constituted in Irish law in 2005.

The Irish quota is managed by allocating individual quotas to vessels on a weekly basis. Participation in the fishery is restricted to licensed vessels. Previously, vessels had to participate in the fishery each year to maintain their licence and since 2004 this requirement has been lifted. This has been one of the contributing factors to the reduction in number of vessels participating in the fishery in recent seasons (Anon, 2005b). Fishing is restricted to the period Monday to Friday each week, and vessels must apply a week in advance before they are allowed to fish in the following week. Triennial spawning box closures are enshrined in EU legislation.

The stock is exploited by two types of vessels, large boats with refrigerated seawater (RSW) storage and smaller dry hold vessels. The small vessels are confined to the spawning grounds (VIIaS and VIIg) during the winter period. The RSW tank vessels target the stock inshore in winter and offshore during the summer feeding phase (VIIg). There has been very little fishing in VIIj in recent seasons compared with the 1980 – 2000 period.

Since 2002 fishing has taken place in quarter 3 (autumn), when fish are targeted during the feeding phase on the offshore grounds around the Kinsale Gas Fields. These fish tend to be fatter and in better condition than winter-caught fish. In 2003 the fishery opened in July on the Labadie Bank. In 2004-2006 it opened in August and in 2007 in September. The July 2003 fishery caught larger fish than are normally found in the fishery. Only RSW and bulk storage vessels can prosecute this fishery. Traditional dry-hold boats are unable to participate because the herring caught tend to deteriorate in quality very quickly.

In recent years, the composition of the fleet has changed considerably. Fleet size has reduced and an increasing proportion of the catch is taken by RSW and bulk storage vessels and less by dry-hold vessels. There has been an increase in efficiency in the fishery since the 1980s with greater ability to locate fish and technical improvements in the fishing gear.

The collapse of the market for herring roe in the 1990s means that there is no longer the same incentive to discard (slip) catches (Table 1.5.1). Estimated landings are shown for the period 1958 – 2008 in Figure 1.6.1

1.6 Assessment and management of Celtic Sea and Division VIIj

1.6.1 Assessment of stock

Based on the final assessment conducted by ICES (2009), the stock history is presented in Figure 1.6.1. It can be seen that spawning stock biomass (SSB) was high in the 1960s and declined in the 1970s as fishing mortality (F) increased and recruitment was poor. Spawning stock biomass (SSB) has declined since the early 1990s and the stock collapsed for a second time in 2004. Since then it has rebuilt to above the precautionary level and ICES (2009) assessment estimated SSB to be 70,000 tonnes in 2009.

Fishing Mortality (F) remained at the same high level and was always above 0.4 since the first stock collapse but has been reduced to low levels in 2007 and 2008. Fishing Mortality in 2009 was at an historic low level.

Recruitment fluctuated at high levels up to 1970s, then at low levels until the early 1980s. The stock rebuilt in the 1980s but not to quite the same level as previously. This rebuilding was due to good recruitments. It returned to high levels again until the late 1990s. Recent recruitment has fluctuated around the long term average (Anon, 2009).

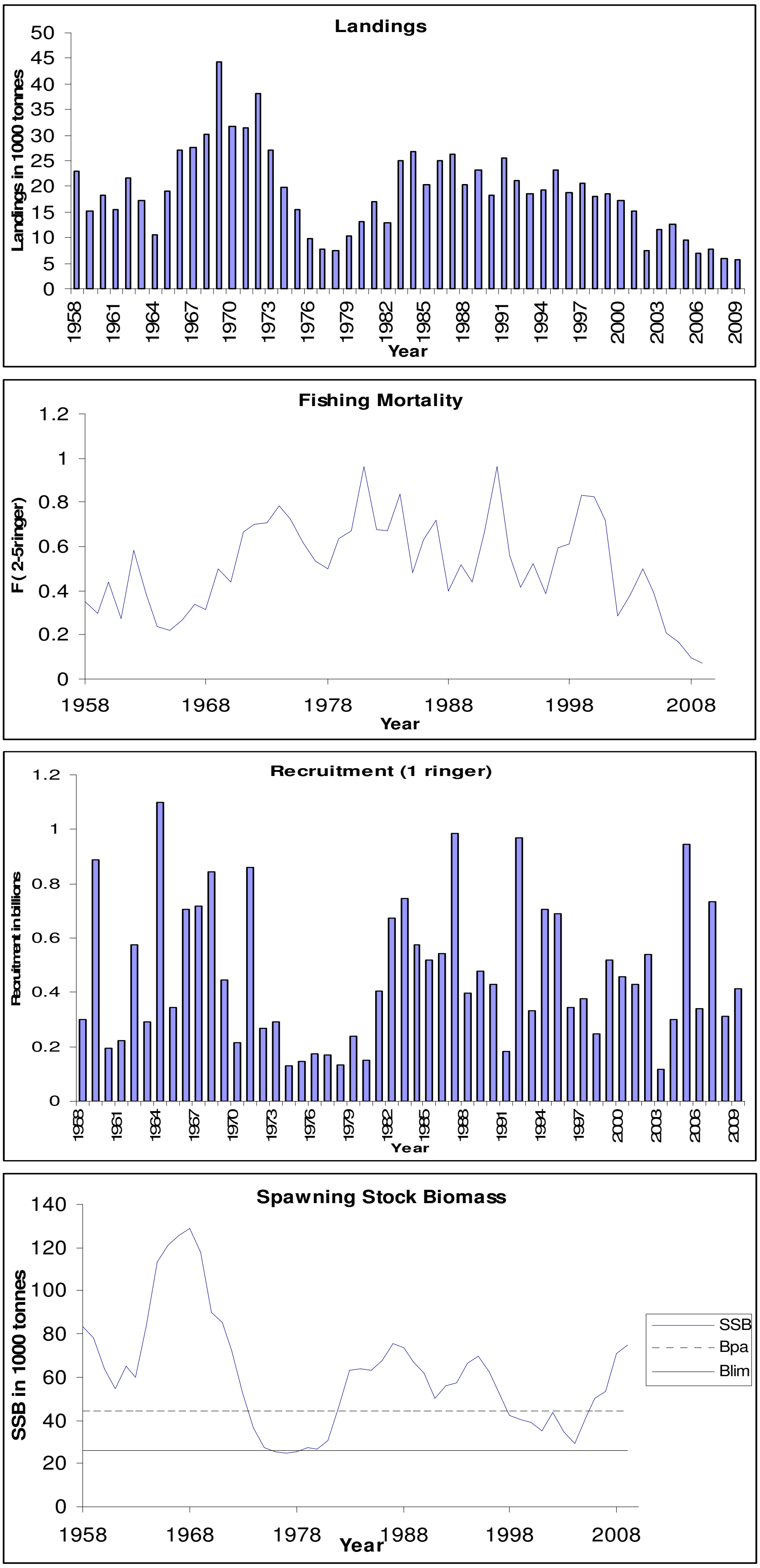


Figure 1.6.1. The Landings, fishing mortality (F), recruitment of 1 ringer (R) and spawning stock biomass (SSB) of Celtic Sea and Division VIIj herring from from final assessment run performed by ICES HAWG in 2009 (Anon, 2009). Lines indicate SSB, Bpa (44000t) and Blim (26000t).

1.6.2 Management of stock

The assessment year is from 1st April to 31st March. However for management purposes, the TAC year is from 1st January to 31st December. Therefore the fishery is managed on a calendar year basis, but the biological data collection and assessment is on a seasonal basis.

Before Ireland's entry into the EU, the herring fishery was managed by the North East Atlantic Fisheries Commission (NEAFC). This body was responsible for the establishment of the quota regime and the allocations of total quotas on a national basis. After Ireland joined the European Economic Community (EEC), NEAFC ceased to have a role in management of the fishery, and instead the EEC Common Fisheries Policy TAC and quota regime was responsible for managing the fishery (Molloy, 1995). The first time that management measures were applied to this fishery was during the late 1960s. This was in response to the increasing catches particularly off Dunmore East. The industry became concerned and restrictions were put in place in order to prevent a glut of herring in the market and a reduction in prices. Boat quotas were introduced restricting the nightly catches and the number of boats fishing. Fishing times were specified with no weekend fishing and herring could not be landed for the production of fishmeal. A minimum landing size of 20cm was also introduced (Molloy, 1995), in order to discourage the landing of juvenile herring.

The TAC (total allowable catch) system was introduced by the NEAFC in 1972, which meant that yearly quotas were allocated. This continued until 1977 when the fishery was closed. During the closure a precautionary TAC was set for Division VIIj.

This division was not assessed analytically (Anon, 1994a). Another significant event took place in 1977. The Irish exclusive fishery limits, like those of the other EU maritime states, were extended to 200 miles, and NEAFC no longer had a role to play in the management of the Celtic Sea herring fishery, (Molloy, 2006). After the re-opening of the fishery in 1982, a new management structure was implemented with catches controlled on a seasonal basis and individual boat quotas were put in place (Molloy 1995).

Table 1.6.2 shows the history of the ICES advice, implemented TACs and ICES' estimates of removals from the stock. The tendency for the TAC to be set higher than the advice has also increased in recent years. It can also be seen that ICES estimates of realised catches have been lower than the agreed TAC in most years.

Table 1.6.2. Advice history of Celtic Sea and Division VIIj herring taken from Anon, 2008a.. TAC and catch estimates are based on calendar years.

Year	ICES Advice	Predicted catch corresp. to advice	Agreed TAC	Official Landings	Discards	Estimated Catch[1]
1974	NEAFC TAC		32	20	-	19.74
1975	Reduce F, TAC ? 25,000		25	16	-	15.13
1976	TAC between 10,000 and 12,000		10.8	10	-	8.2
1977	No Fishing	0	0	8	-	3.0
1978	No Fishing	0	0	8	-	7.1
1979	TAC set for VIIj only, No fishing in Celtic Sea	0	6	10	-	12.1
1980	TAC set for VIIj only, No fishing in Celtic Sea		6	9	-	9.2
1981	TAC set for VIIj only, No fishing in Celtic Sea		6	17	-	16.8
1982	TAC		8*	10	-	9.5
1983	TAC		8*	22	4.0	22.18
1984	TAC	13	13	20	3.6	19.7
1985	TAC	13	13	16	3.1	16.23
1986	No specific TAC, preferred overall catch 17,000t		17	13	3.9	23.3
1987	Precautionary TAC	18	18	18	4.2	27.3
1988	TAC	13	18	17	2.4	19.2
1989	TAC	20	20	18	3.5	22.7
1990	TAC	15	17.5	17	2.5	20.2
1991	TAC (TAC excluding discards)	15 (12.5)	21	21	1.9	23.6
1992	TAC	27	21	19	2.1	23
1993	Precautionary TAC (including discards)	20–24	21	20	1.9	21.1
1994	Precautionary TAC (including discards)	20–24	21	19	1.7	19.1
1995	No specific advice	-	21	18	0.7	19
1996	TAC	9.8	16.5–21	21	3	21.8
1997	If required, precautionary TAC	< 25	22	20.7	0.7	18.8
1998	Catches below 25	< 25	22	20.5	0	20.3
1999	F = 0.4	19	21	19.4	0	18.1
2000	F < 0.3	20	21	18.8	0	18.3
2001	F < 0.34	17.9	20	19	0	17.7
2002	F<0.35	11	11	11.5	0	10.5
2003	Substantially less than recent catches	-	13	12	0	10.8
2004	60% of average catch 1997–2000	11	13	12	-	11
2005	60% of average catch 1997–2000	11	13	10	-	8
2006	Further reduction 60% avg catch 2002–2004	6.7	11	9	-	8.5
2007	No fishing without rebuilding plan	--	9.3		-	8.2
2008	No targeted fishing without rebuilding plan	--	7.9			
2009	No targeted fishing without rebuilding plan	--				

* TAC from 1st Oct – 31st Mar

1) Calendar year

1.7 Scope and purpose of the study

The Celtic Sea herring stock has supported commercial fisheries for centuries. The stock has undergone cycles in its status, with periods of high and low abundance. It has collapsed twice, most recently in 2004. Despite the effort put into assessing the stock, little attention has been paid to analysing the basic biological data. This is despite the fact that the biological data has been collected routinely since the 1950s.

This study will collate, for the first time, biological data for the stock. These data will be used to investigate long term trends in key biological parameters: length at age, weight at age, maturity at age, condition factor and growth rate. In addition, the trends in these parameters will be analysed in the context of environmental factors: Sea surface temperature, North Atlantic Oscillation and *Calanus* abundance and these will be compared with long term trends in biology. This study will be the first step to elucidate biological trends in terms of environmental and fisheries drivers.

This study will provide new information on cycles in size and weight at age, condition and growth rate of a heavily exploited herring stock, at the southern margin of the species' distribution. These changes have implications for its future management of the fishery. It is hoped that the results of this study will facilitate a better understanding of stock productivity and can inform management decisions about the future exploitation of this important resource.

2. MATERIALS AND METHODS

Unless otherwise stated in this thesis, age is referred to in winter rings. For this stock 1 winter ring (ringer) = 2 year old, (see Appendix IV).

Unless otherwise stated the fishing year refers to the fishing season. Therefore Q4 1960 and Q1 1961 (1960/1961 season) is referred to as "1960". Environmental data were structured to correspond to the relevant fishing season.

Throughout this work all reconstructed data refers to quarters 4 and 1 only. The term "reconstructed data" refers to data that were derived from archival work conducted in this study, and not data previously used in ICES.

2.1 Sampling Procedure

The data used for this study were collected from the Celtic Sea herring commercial fishery from 1959 – 2007 inclusive. These samples were obtained from the Irish fishery which has been, since the late 1950s, the main country to exploit the stock. In the early 1950s the main gear type used was the traditional driftnet. This was replaced gradually by mid-water trawls from 1960 onwards. In the mid to late 1950s some fishing also took place using ringnets (Molloy, 2006). Most of the samples used in this study were caught by pelagic vessels using mid-water pair trawling method or mid-water single trawling method. The fishing grounds in the Celtic Sea are shown in Figure 1.4.4

Scientists from the Marine Institute and its predecessors sampled the herring according to a standardised protocol, see section 2.2. Samples were obtained from commercial landings. Constant contact has been maintained, over the years, with fishermen, buyers, processors and fisheries officers to ensure that sufficient samples were obtained throughout the fishing seasons. The number of samples per year and the gear type used are shown in Table 2.1

Table 2.1. Number of samples per fishing season and main gears.

Year	Number of Samples	Fishing Gear used
1959/1960	1	Pair mid-water trawl
1960/1961	2	Pair mid-water trawl
1961/1962	1	Pair mid-water trawl
1962/1963	18	Pair mid-water trawl; Bottom trawl
1963/1964	47	Pair mid-water trawl
1964/1965	40	Pair mid-water trawl; Bottom trawl; Driftnet
1965/1966	26	Pair mid-water trawl
1966/1967	34	Pair mid-water trawl
1967/1968	39	Pair mid-water trawl; Bottom trawl
1968/1969	35	Pair mid-water trawl; Bottom trawl
1969/1970	48	Pair mid-water trawl
1970/1971	44	Pair mid-water trawl; Bottom trawl
1971/1972	26	Pair mid-water trawl; Driftnet
1972/1973	25	Pair mid-water trawl; Driftnet
1973/1974	17	Pair mid-water trawl
19741975	19	Pair mid-water trawl; Driftnet
1975/1976	26	Pair mid-water trawl
1976/1977	12	Pair mid-water trawl
1977/1978	11	Pair mid-water trawl
1978/1979	25	Pair mid-water trawl; Driftnet
1979/1980	46	Pair mid-water trawl; Drift net
1980/1981	37	Pair mid-water trawl; Driftnet
1981/1982	30	Pair mid-water trawl; Driftnet
1982/1983	45	Pair mid-water trawl
1983/1984	59	Pair mid-water trawl; Bottom trawl; Driftnet
1984/1985	70	Pair mid-water trawl
1985/1986	40	Pair mid-water trawl
1986/1987	52	Pair mid-water trawl
1987/1988	79	Pair mid-water trawl
1988/1989	117	Pair mid-water trawl
1989/1990	121	Pair mid-water trawl
1990/1991	86	Pair mid-water trawl
1991/1992	109	Pair mid-water trawl
1992/1993	86	Pair mid-water trawl
1993/1994	61	Pair mid-water trawl
1994/1995	74	Pair mid-water trawl
1995/1996	73	Pair mid-water trawl
1996/1997	82	Pair mid-water trawl
1997/1998	83	Pair mid-water trawl
1998/1999	58	Pair mid-water trawl
1999/2000	66	Pair mid-water trawl
2000/2001	39	Pair mid-water trawl
2001/2002	123	Pair mid-water trawl
2002/2003	34	Pair mid-water trawl
2003/2004	43	Pair mid-water trawl
2004/2005	42	Pair mid-water trawl
2005/2006	42	Pair mid-water trawl
2006/2007	61	Pair mid-water trawl

2.2 Sampling Protocol

The basic sampling protocol has remained almost completely unchanged since 1958. Length, sex and maturity were recorded, and otoliths extracted for ageing purposes. In 1975 a change occured with the introduction of recording the weight of the fish. Samples were collected throughout each fishing season, therefore representing fishing of the various areas, time periods and gear types. Samples were obtained where possible, from vessels landing fish into port. This process was not necessarily random, but every attempt was made to obtain as broad a range of samples from as many different boats as possible.

Individual samples were selected randomly from the ungraded bulk landing of a particular vessel. These samples were obtained directly from boats, or from fish processors. In all cases, the identity of the vessel was recorded. Important information such as the boat name, ICES area, fishing ground, and fishing gear was recorded (see Appendix I for record sheet example). Weighing scales were calibrated, using a calibration weight. All fish in the sample were measured and a random sub-sample of 50 to 75 fish was taken, for ageing. In all seasons, except the years 2003/2004, the aged sample was obtained randomly (see Annex 1). In 2003/2004, 5 fish per half centimetre length class chosen for ageing (length stratified sampling). The total length (TL) of the fish was measured to the nearest half centimetre below, from the tip of the snout to the tip of the tail, along the main linear axis of this fish. The body weight was then recorded to the nearest 0.5g. The fish were then dissected to determine sex and maturity. This incision was made from the eye to the tail of the fish with the scalpel running alongside the back bone. This particular technique was used originally to count the vertebrae. To determine the stage of maturity, the standard ICES scale (Landry and McQuinn, 1988; Anon 2003) was followed (Appendix II).

2.3 Estimation of age

The saggital otoliths are one of three pairs of otoliths found in membranous labyrinth of Osteichthyan fishes (Panfili, 2002). The herring otolith is an elongate structure. An incision was made above the eye and through the brain of the fish to expose the saggital otoliths in the cranium. These were extracted from the cranium using a fine forceps, as shown in Figure 2.3.1. Otoliths were then washed, dried and placed in a labelled tray.

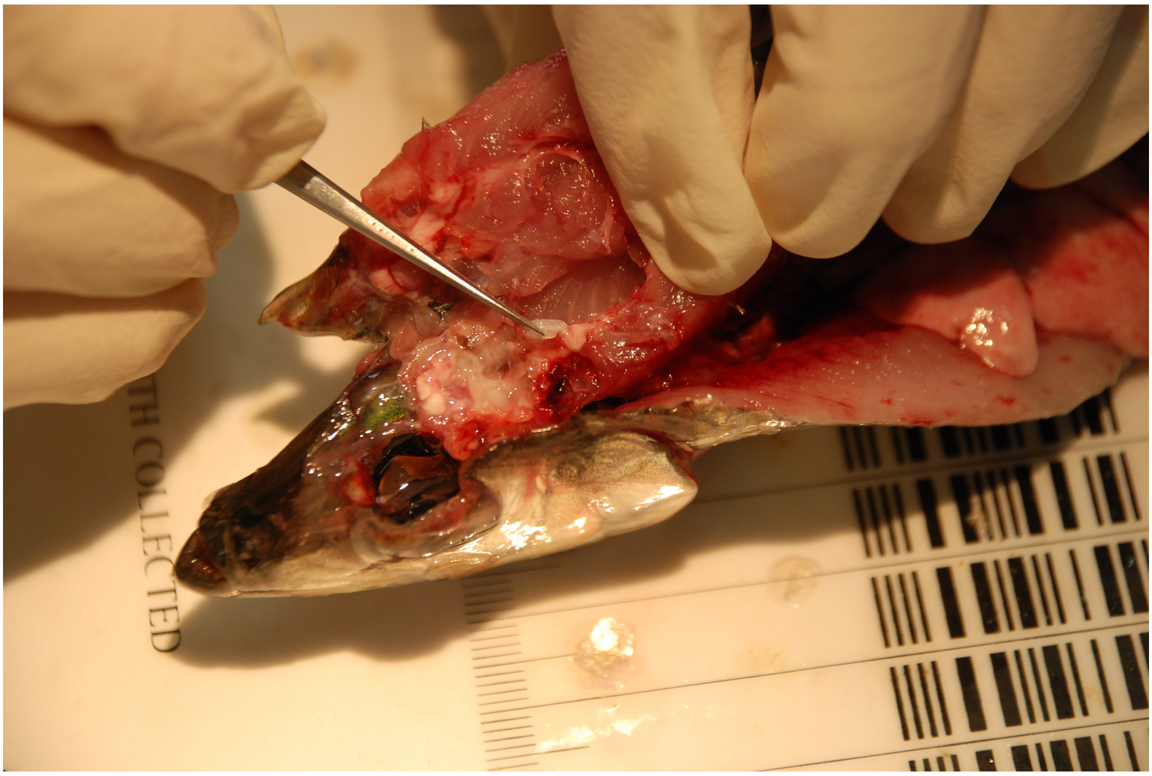


Figure 2.3.1 The extraction of the otoliths from the cranium of a Celtic sea herring.

2.3.1 <u>Otolith Preparation</u>

Herring otoliths are thin and transparent so they are read flat. A black mounting tray was used for the otoliths from each sample. The pairs of otoliths were placed in the numbered cavities accordingly, using a fine forceps. They were positioned, as a mirror image of each other with the concave side up as shown in Figure 2.3.2. It was important that the otoliths were clean and dry so they would set appropriately in the medium. Histokitt© mounting medium was then added to the cavities using a plastic pipette and the otoliths were rearranged with a seeker, into the appropriate positions. They were then checked with a magnifying glass or microscope to ensure that they were positioned correctly. They were then left to set and dry.

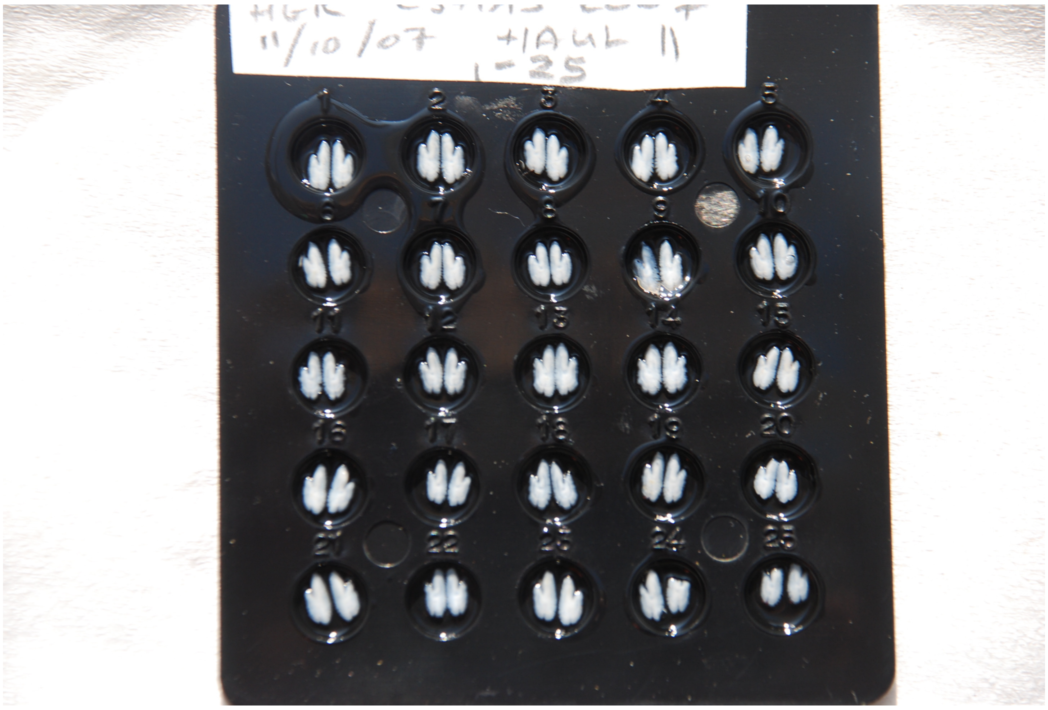


Figure 2.3.2. Celtic sea herring otoliths mounted with histokitt© in a black mounting tray.

2.3.2 <u>Age Reading</u>

Internationally all readers use The Glossary for Otolith Studies (1995) as a basis for the methodology of age reading (Kalish J.M. *et al*, 1995). The otoliths were viewed using a stereoscopic microscope that in recent years was a Leica Zoom 2000©, using reflected light. The minimum level of magnification (15x) was used initially. It was then increased to resolve the features of the otolith. No standard magnification was used for herring otolith reading, and each reader had certain preferences. However, reading was in the range of 20x – 25x. The pattern of opaque (summer) and translucent (winter) zones was viewed and an example of a herring otolith viewed under a microscope is seen in Figure 2.3.3. The last winter (translucent) ring at the otolith edge was counted only in otoliths from fish caught after the 1st April. This "birth date" was used because the assessment year for Celtic Sea and division VIIj herring runs from 1st April to the 31st March of the following year (Anon, 2007). This ageing and assessment procedure is unique in ICES, to this herring stock. The first winter ring counted is that which corresponds to the second "birth date" of the fish because the first winter is usually spent during the larval phase. Therefore a fish of 2 winter rings is referred to as a 3 year old. This convention applies to all ICES herring stocks with autumn spawning components (See Appendix IV).

Since 1958, only six age readers have been involved in ageing. Table 2.3.2 shows the names of these readers and the years in which they were active. The first reader, Professor John Bracken was taught this ageing method in CEFAS, Lowestoft, UK, in the 1950s. International age reading workshops were held to ensure consistency between readers in IJmuiden (Anon, 1994b) and Finland (Anon, 2005a). The ICES Herring Working Group proposed in 1991 that an otolith exchange programme should be initiated in each of the major fishing areas in order to check the quality of the age determination in various national laboratories (Anon., 1991). The results were analysed using a spreadsheet programme designed by Guus Eltink, RIVO, Ijmuiden (Eltink, 1994). This spreadsheet is considered to be the standard method of analysing precision and accuracy. It is the tool used internationally for the analysis of age determination results by individual readers (http://www.efan.no) and has been used in the Marine Institute since 1994 when John Molloy (Table 2.3.2) was still involved in age reading herring (Anon, 1994). See Appendix V.

Tables and bubble charts of percentage numbers of fish at age (winter rings) were produced. These were constructed for the combined stock area and also for each ICES division separately, over the entire time series. This was conducted to track strong cohorts, to compare cohort dynamics between the three areas and to show how they differ over time.

Table 2.3.2. Age readers for Celtic Sea herring over the time series.

Years	Reader
1960 - 1964	John Bracken
1960 - 1964	Mattie Foster
1964 - 2004	John Molloy
1980 - 1990	Liz McArdle
1980 - 1999	Liz Barnwall
2002 - 2009	Deirdre Lynch

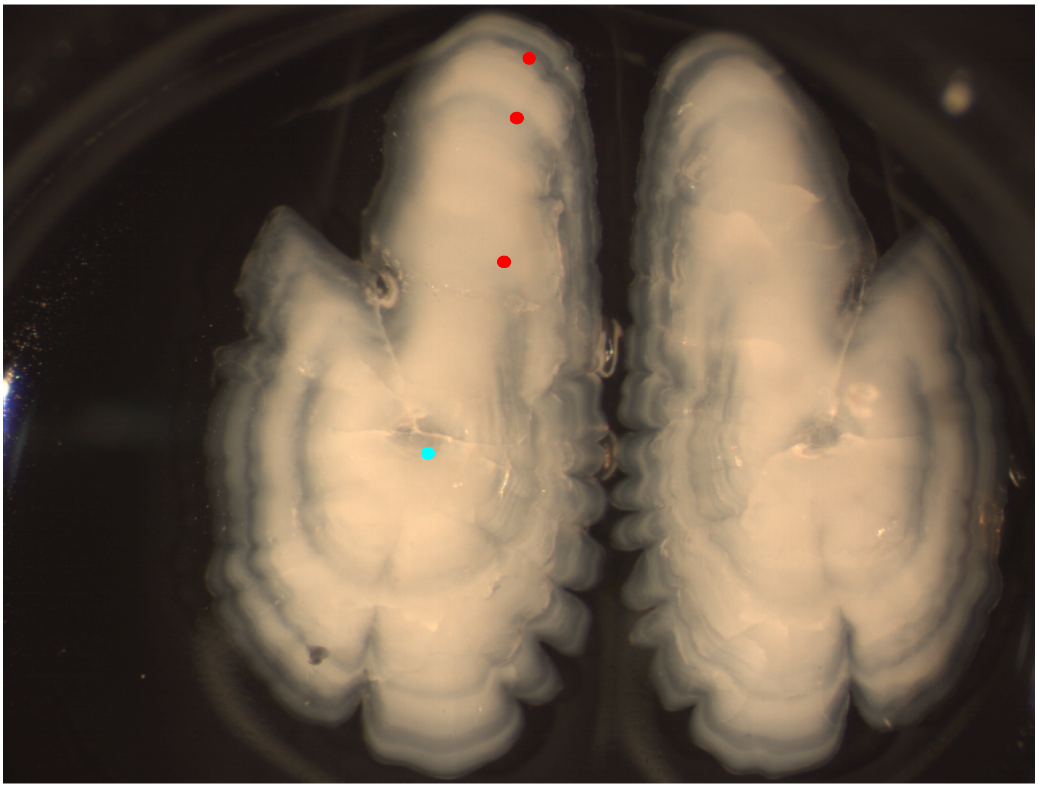


Figure 2.3.3. Otoliths taken from a herring from ICES Division VIIg in October 2005 showing the winter rings in red and the nucleus in blue. There are 3 winter rings present. These otoliths were viewed under a stereoscopic microscope using between 20x and 25x magnification.

2.4 Data input and storage

This study was the first to compile the biological data for this stock. The data were present in paper form and although the summary information was compiled each year and reported to ICES, the original data were not archived electronically. The only biological data not collated were those from foreign (mainly Dutch) catches from this stock. Whether these data still exist on paper or other format is unknown. It is known that most of the Dutch catches (mainly 1960s/1970s) came from the Irish coast also (Molloy, 1969) and it can be concluded that the size and age structure would be similar. However, the data that have been archived cover the main fishing country (Ireland) and all the known spawning grounds. Therefore the present dataset can be used to show trends over time in the stock at spawning time (quarter four and quarter one). Environmental data were obtained from online sources that corresponded with the biological data. In addition, data on stock status were obtained from the most recent assessment of this stock (Anon, 2009).

2.4.1 Biological data quality

The input of these data into the Stockman database took 26 man months. Validation and editing of the data took place over a further 6 man months. The data from 1960 to 2007 were checked and in total 2354 samples were digitised, comprising 108,721 age readings and 354,902 length measurements. All paper records of herring samples taken from this stock by Irish scientists have been entered.

Some of the data that were inputted were available on 5¼ inch floppy discs (1982-1985) or recovered onto CDs and needing checking (1986-1990; 1994-1999). From 1991-1993 data existed on 3½ floppy discs and finally from 1999 to 2002 the data existed on a stand alone desktop machine (Costello *et al.*, 2004). These data were stored in the old “Sensible Solution” database formats. Initially it was considered a good idea to upload these data to a database and extract the biological data from them. However it was unclear if all discs were still in existence and furthermore, data from 1959 to 1981 were only recorded on paper. Therefore it was decided to input all the data directly from paper to the “Stockman” database. This process allowed for important biological information to be transcribed from hand-written records.

The commercial data from 1959 to 1980 were in paper records only. The data from 1980 to 1986 were also stored electronically on 5¼-inch floppy discs. From 1986 to 2003 the data were inputted onto the “Sensible Solution” database and from 2003 onwards the data were inputted onto the “Stockman” database. The Sensible Solution database was a MS DOS based application, which was developed in the early 1980s by Richard Grainger for the Fisheries Research Centre. The Stockman database was designed in 2002 to incorporate all types of commercial fisheries data into one database where they could be extracted and analysed. The Stockman database is a relational SQL Server 2000 database.

The data from 1959 to 2007 were inputted manually on to the Stockman database from the original paper records. This included the data also contained on the floppy discs and on the Sensible Solution database because it would have proved equally time consuming to transfer it electronically to the Stockman database.

2.4.2 <u>Data entry</u>

The following information was inputted into Stockman for each sample:

- Sampling Trip Metadata: Sample Place, Landing Place, Sample Name, Recorder Name and Inputter Name.
- Sample Metadata: Sampling Date, Vessel Name, ICES Division, Ground Name, Gear Type and Catch Type.
- Species Metadata: Species Name, Sample Presentation Type, Measurement Units, Samples Quality, Sampling Type and Size Catogory.
- Morphometric Details: Measured Data, Morphometric Data and Age Analysis.

For each sample, the length frequency for the aged data was summed and added to the "measured only" data. The total length frequency was then inputted into Stockman. Finally for each sample, the length, weight, sex, maturity, vertebrae count (when available) and age information was entered onto the database.

All the data were extracted per ICES area and per quarter and examined as part of the validation exercise. Any outliers were then compared to the original data sheets and edited in Stockman where necessary. An example of the stockman data fields are shown in Appendix III

2.4.3 Data Extraction

Stockman summaries were then extracted from the Stockman extraction module. This module was designed as an add-on to the main Stockman database. The criteria selected for the summaries are as follows:

- Species: herring
- ICES Area: VIIa South, VIIg, VIIj
- Gear Type: All
- Size Category: Unsorted
- Date Boundary: Per year or per quarter

Each extraction produced a six-part summary (see Appendix III). The fish catch summary displayed the number of measured samples, the number of aged samples, the unique sample numbers and the extraction criteria used. This was then checked against the raw data sheets for the same year and quarter to make sure all samples were included in the extraction. The extractions also showed a list of the boats involved, a length frequency table, a length frequency graph and the raw data. The raw data and graph were checked for any abnormalities such as obscure lengths in the distribution. If any were found, it was then checked against the raw data sheets and edited where necessary. The length weight regression display showed the sample number, length, weight, age, corrected length, log of length, log of weight and the slope and intercept of the length weight regression. The corrected length for herring is the recorded length plus 0.25 cm because the herring was measured in 0.5cm. The extra 0.25 cm is to represent the mid-point of the length class. A scatter plot of corrected length and corrected weight (from length weight relationship) was also displayed. Any outliers were highlighted in red and were checked against raw data sheets. The necessary edits were made in Stockman and the summary was re-extracted. The age length key display showed the number of fish by age and by length. Any length classes that were present in the length frequency but were absent from the aged data were highlighted. These "gaps" were filled in using data from the same quarter and from the nearest year to the year being extracted. The fill-ins showed up in red so they could be easily identified and the source of the fill-in was then recorded in the comment box. This is a standard operating procedure in ICES, and has been used for this stock since the beginning of the time series. Recent statistical approaches to filling in have not yet been applied and cells in an ALK with insufficient data have prevented statistical analyses of age length keys (Gerritsen *et al.* 2006).

It was decided that 1000 tonnes would be used as an arbitrary landed weight for all the summaries extracted in order to obtain the biological data. The length weight distribution showed length, number sampled, mean weight observed, mean weight expected, weight sampled, number landed and weight landed. The catch numbers at age show numbers landed at each age group and the percentage distribution of each age group together with the mean length and mean weight. There is also a Sum of Product (SOP) calculated by the database and this should be 100%. The SOP acts as a check to ensure that all necessary fill-ins have been updated in the age length key and that the Catch numbers at age has been calculated correctly. The SOP is calculated automatically as follows: Total Landings/(Sum (No of fish at age*mean weight of fish at age)).. All information was checked on the summary and then saved to an excel spreadsheet. (For more information on the calculations of the summary see Appendix III)

2.5 Mean length and weight at age

2.5.1 Mean lengths

The mean lengths at age were reconstructed from archive data. They were tabulated and plotted showing the trends from 1960 to 2007. The mean lengths at age from Burd and Bracken (1965), and references therein, were also tabulated and plotted showing the trend from 1921 to 1964. Both tables were combined and plotted to show the mean lengths at age from 1921 to 2007.

2.5.2 Mean Weights

The mean weights at age were reconstructed from archive data and tabulated. These were plotted to show the trend from 1975 – 2007. In addition, the mean weight at age in the catch was taken from the latest ICES Herring Assessment Working Group for the areas south of 62^{o}N (HAWG) Report (Anon, 2009). This was tabulated and plotted. The main difference between these two "mean weight-at-age" tables and "mean weight-at-age" graphs is the weight, to which the catches were raised. In the ICES HAWG Report (Anon, 2007), the official landed weights were used and these included landed weights from foreign landings. In the Stockman mean weight at age, 1000 tonnes was used as an arbitrary landed weight and there were no samples from foreign landings included in the data set.

2.5.3 Further statistical analyses

The mean length and mean weight at age were derived from Stockman, based on mean values, weighted by catch numbers, for a given extraction. Thus, mean length at 2 winter ring in 1974/1975 was derived from the mean of catch numbers at that age, weighted by the catch numbers at length at that age. This procedure is automated in Stockman. Further statistical tests were beyond the scope of this project.
An example of an extraction from Stockman is presented in Appendix III and a description is given for each step.

2.6 Length Weight Relationship and condition factor

The parameters of the length weight relationship from 1975 to 2007 were tabulated along with the number of fish weighed and the r^2 value. Weight data was only available from 1975 onwards. These parameters were taken from the length weight regression part of each summary where the natural log (Ln) values of the corrected (mid-point) lengths were plotted against the natural log values of the weights. Linear regression (type I) was used to obtain the slope, intercept and r^2 value. The r^2 value indicates the degree to which the regression represents the spread of the data, or the extent to which the variation in the data agrees with the fitted line.

Length weight relationships using type I regression (Ricker, 1975) were used throughout. These relationships take the form of:

$\ln W = \ln a + b \ln L$

where: W = weight in g

L = total length measured to the half cm below

a = intercept

b = slope

To derive an index of condition of individual cohorts, mean length and mean weight at age data were used. Fulton's condition factor (Ricker, 1975) was applied to these data as follows:

$$F_{c,a} = mw_{c+a} / ml_{c+a}^{3}$$

Where:

F = Fulton's condition factor

c = cohort born in year c, where c denotes the first year, thus 1974 = 1974/1975

a = age in years = age in winter rings + 1

mw = mean length at age (winter rings)

ml = mean length at age (winter rings)

This condition factor compares the observed weight to an "idealised" weight based on isometric growth, where the length weight relationship slope, b = 3.

2.7 Maturity Ogives

Raw data (length, age, sex and maturity) from 1962 to 2006 of archived data was extracted by fishing season (e.g. 1975 = Q4 1975 and Q1 1976). The data were then filtered to separate males from females. An extra column was added to allocate mature/immature to each data record depending on its maturity stage. Maturity stages 1 and 2 are considered immature and maturity stages 3 – 8 are considered mature.

From this, the maturity and the age (winter rings) were collated to show the total numbers as well as the numbers immature and mature at each winter ring. The percentage maturity was calculated by dividing the numbers mature by the total numbers at each winter ring. The percentage maturity at age (in winter rings) was then tabulated by fishing season from 1962 – 2006 and the percentage maturity at 1 winter ring and 2 winter ring for males and females was plotted graphically.

2.8 Absolute Growth Increment

Absolute growth increments were calculated from the time series of the reconstructed data. Mean weight and mean length at age data were used to estimate absolute growth rate, by year class. From the extracted data absolute growth rate was estimated, in terms of mean weight or mean length, by the following equation:

$I_m = \mathrm{Ln}\ ((\mu,_{y+1} - \mu_y)+2)$

Where

I	=	increment
m	=	weight (g) or total length (cm) measurement
μ	=	mean weight or mean length
Y	=	year

The log transformation was performed by the addition of 2 to account for apparent negative growth, especially at older ages. This analysis was performed for 2-5 winter ring interval. This was to measure growth over the main age groups in the population, as these have always been 2 to 5 winter ring fish (Anon, 2008a, Annex 5).

A median value for the growth increment in 3 ringer fish was calculated for mean lengths and mean weights. The 3 ringer group was chosen because it is the dominant age throughout the time series. The growth increments above and below this median value were separated and plotted graphically to define fast and slow growing cohorts. This median was chosen to illustrate graphically fast (above median) and slow (below) growing cohorts with reference to the dominant age group (3 ringer).

2.9 Environment of the Celtic Sea

2.9.1 Temperature

The Sea Surface Temperature (SST) data used in this study were extracted from a grid dataset (Second Hadley Centre Sea Surface Temperature dataset (HadSST2)). The digital data file was obtained from www.cru.uea.ac.uk/cru/data/temperature HadSST2 was based on data contained within the recently created International Comprehensive Ocean–Atmosphere Data Set (ICOADS). Full information regarding the makeup of the ICOADS database can be found in the online documentation at http://www.cdc.noaa.gov/coads/. Full information regarding the makeup and other information about the HadSST2 is presented by Rayner *et al*. (2005).

The sea surface temperature in the Celtic Sea was recorded every month from 1970 to 2003 and an average for each year was calculated. These averages were plotted to show the trend from 1970 to 2003. Table 2.9.1.1 shows the mean monthly SST for the Celtic Sea since 1970 by fishing season and Table 2.9.1.2 shows the mean monthly SST for the Irish Sea since 1970 by fishing season.

Table 2.9.1.1 Monthly mean Sea Surface Temperature (°C) for the Celtic Sea, by fishing season

	Quarter 2			Quarter 3			Quarter 4			Quarter 1		
Year	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
1970/1971	9.91	11.36	14.64	15.32	16.45	15.50	14.05	12.35	11.38	10.50	10.21	9.99
1971/1972	10.35	11.51	13.12	16.19	16.65	16.51	15.62	13.13	11.62	10.61	9.79	9.68
1972/1973	10.04	10.66	12.02	15.00	16.00	15.82	14.20	12.08	10.90	10.37	9.92	9.85
1973/1974	10.20	11.41	13.86	16.15	16.76	16.50	14.29	12.57	11.18	10.46	10.08	9.87
1974/1975	10.75	11.55	13.56	15.72	16.30	14.94	12.69	11.48	10.92	10.73	10.32	9.83
1975/1976	10.04	11.33	13.98	16.57	17.91	16.50	14.16	12.80	11.10	10.57	9.98	9.79
1976/1977	10.22	11.49	14.17	17.23	18.80	17.12	14.20	11.83	10.60	9.91	9.61	9.90
1977/1978	9.93	11.50	13.81	15.88	16.83	15.66	14.26	12.36	11.10	10.19	9.58	9.62
1978/1979	9.83	11.27	13.58	14.85	16.63	16.50	14.72	13.57	11.63	9.98	9.30	8.93
1979/1980	9.28	10.61	13.64	15.80	16.13	15.96	14.35	12.28	11.35	10.19	9.94	9.69
1980/1981	10.38	12.04	14.25	15.38	16.68	16.28	13.88	11.96	11.01	10.25	9.92	9.96
1981/1982	10.57	11.46	13.79	15.83	17.33	16.83	13.53	12.14	10.83	10.09	10.01	9.61
1982/1983	10.38	11.72	14.43	16.89	17.16	15.81	13.77	12.14	10.94	10.30	9.63	9.74
1983/1984	9.69	10.97	13.71	16.86	18.12	15.79	14.30	12.79	11.70	10.63	9.88	9.55
1984/1985	10.29	11.72	13.71	16.61	18.12	16.93	14.21	12.48	11.38	10.23	9.86	9.61
1985/1986	10.31	11.26	13.99	16.31	15.53	15.37	14.84	12.62	11.38	10.30	9.13	9.09
1986/1987	9.02	10.23	12.51	15.52	15.61	15.00	14.26	12.05	10.69	9.61	9.34	9.43
1987/1988	10.12	11.68	13.69	16.60	17.66	16.38	13.95	12.28	11.21	10.75	9.97	9.69
1988/1989	10.29	11.82	14.30	15.48	15.95	15.51	13.54	12.58	11.57	11.09	10.71	10.27
1989/1990	10.23	12.28	15.39	18.03	18.04	16.79	15.17	12.80	11.58	11.05	10.57	10.46
1990/1991	10.67	13.35	14.75	16.32	18.04	16.69	14.81	12.73	11.27	10.21	9.68	9.85
1991/1992	10.34	11.66	13.20	15.89	17.38	17.47	13.98	11.83	11.28	10.68	10.26	10.07
1992/1993	10.01	11.93	15.01	16.99	16.60	15.05	13.46	11.66	10.81	10.43	10.30	10.06
1993/1994	10.42	11.88	14.07	15.92	16.27	15.98	13.11	11.49	10.40	9.81	9.25	9.30
1994/1995	9.87	11.37	13.29	16.01	16.71	15.00	13.76	12.71	11.80	10.36	10.24	9.76
1995/1996	10.41	11.95	14.58	17.42	19.28	17.35	15.34	13.62	11.54	10.73	9.77	9.73
1996/1997	10.39	11.00	13.53	15.79	17.05	16.60	14.45	12.37	10.93	9.90	10.04	10.18
1997/1998	11.28	12.43	15.08	17.29	18.75	16.95	15.75	13.91	12.22	11.32	10.96	10.64
1998/1999	10.73	12.64	14.31	15.99	17.17	16.69	14.83	12.45	11.65	11.11	10.65	10.51
1999/2000	10.93	12.54	14.55	16.84	17.91	17.12	14.81	12.98	11.43	10.61	10.48	10.50
2000/2001	10.58	12.66	14.07	16.26	17.74	16.85	14.26	11.68	11.34	10.64	10.28	9.97
2001/2002	10.60	12.53	15.13	17.10	17.76	17.34	15.53	13.68	12.27	11.43	11.16	10.98
2002/2003	11.45	12.19	14.10	15.64	17.74	17.54	15.73	12.99	11.45	10.75	10.28	10.55
2003/2004	11.52	12.14	14.87	17.09	18.65	17.87	15.73	12.97	12.02	10.97		

Table 2.9.1.2 Monthly mean Sea Surface Temperature (°C) for the Irish Sea, by fishing season.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1970/1971	7.80	9.75	12.92	13.60	14.58	14.20	13.35	11.62	10.05	8.39	7.51	7.25
1971/1972	8.04	9.65	11.39	14.15	14.68	15.00	14.52	12.27	10.16	8.32	7.04	6.84
1972/1973	7.77	9.03	10.67	13.30	14.40	14.62	13.55	11.47	9.65	8.17	7.21	7.18
1973/1974	7.90	9.68	12.03	14.23	14.83	15.04	13.51	11.80	9.80	8.16	7.28	7.07
1974/1975	8.24	9.74	11.83	13.86	14.58	13.85	12.31	11.01	9.61	8.45	7.52	7.12
1975/1976	7.68	9.34	12.08	14.51	15.69	14.91	13.36	11.97	9.68	8.24	7.11	6.99
1976/1977	7.88	9.58	12.33	15.14	16.51	15.46	13.50	11.39	9.47	7.81	6.88	7.18
1977/1978	7.71	9.68	12.03	13.84	14.88	14.29	13.45	11.60	9.68	8.09	6.90	6.95
1978/1979	7.71	9.59	11.94	13.16	14.79	15.02	13.80	12.63	10.13	7.80	6.61	6.26
1979/1980	7.05	8.74	11.76	13.64	14.25	14.47	13.60	11.58	10.09	8.12	7.26	7.02
1980/1981	8.12	10.13	12.44	13.61	14.86	14.95	13.20	11.27	9.62	8.08	7.01	7.14
1981/1982	8.12	9.55	11.99	13.81	15.12	15.09	12.77	11.35	9.40	7.82	7.06	6.83
1982/1983	8.02	9.74	12.71	14.80	15.17	14.41	13.17	11.52	9.63	8.08	6.90	6.93
1983/1984	7.35	9.12	11.84	14.44	15.64	14.36	13.41	11.88	10.18	8.30	7.11	6.79
1984/1985	7.97	9.77	12.04	14.53	15.82	15.25	13.56	11.82	9.99	7.98	7.05	6.85
1985/1986	7.88	9.33	12.11	14.32	14.03	14.10	13.94	11.76	9.90	7.99	6.42	6.42
1986/1987	7.03	8.64	11.06	13.69	13.85	13.59	13.42	11.39	9.40	7.49	6.62	6.76
1987/1988	7.90	9.87	11.90	14.49	15.48	14.80	13.27	11.60	9.88	8.44	7.21	6.98
1988/1989	7.96	9.93	12.46	13.56	14.25	14.26	12.89	11.69	10.13	8.74	7.86	7.55
1989/1990	7.91	10.28	13.25	15.70	15.83	15.21	14.14	12.02	10.24	8.80	7.76	7.75
1990/1991	8.35	11.05	12.81	14.43	15.89	15.10	13.82	12.00	9.92	8.16	7.11	7.15
1991/1992	8.03	9.72	11.59	14.15	15.56	15.81	13.28	11.23	9.94	8.40	7.49	7.27
1992/1993	7.83	10.14	13.15	14.93	14.85	14.08	12.81	11.02	9.53	8.22	7.52	7.31
1993/1994	8.25	9.99	12.27	14.01	14.39	14.62	12.62	10.90	9.17	7.77	6.70	6.72
1994/1995	7.72	9.67	11.67	14.19	14.88	13.88	13.00	11.88	10.35	8.19	7.58	7.16
1995/1996	8.09	9.89	12.69	15.22	17.06	15.90	14.28	12.64	10.05	8.40	7.00	6.89
1996/1997	7.97	9.15	11.76	13.88	15.06	15.23	13.78	11.70	9.64	7.69	7.25	7.45
1997/1998	8.58	10.41	13.10	15.07	16.38	15.23	14.44	12.78	10.63	8.92	8.17	7.84
1998/1999	8.37	10.49	12.23	13.75	14.83	15.06	13.86	11.67	10.29	8.74	7.63	7.50
1999/2000	8.40	10.37	12.50	14.66	15.58	15.42	13.88	12.12	9.98	8.46	7.67	7.62
2000/2001	8.23	10.51	12.21	14.21	15.51	15.17	13.52	11.03	10.00	8.47	7.60	7.29
2001/2002	8.33	10.54	13.05	15.01	15.70	15.66	14.64	12.76	10.77	9.09	8.35	8.09
2002/2003	8.85	10.27	12.40	13.85	15.59	15.86	14.66	12.18	10.06	8.54	7.49	7.70
2003/2004	8.90	10.26	12.97	15.06	16.43	16.18	14.56	12.21	10.61	8.75		

2.9.2 North Atlantic Oscillation (NAO) data

North Atlantic Oscillation (NAO) is a dominant pattern of atmospheric circulation variability. It refers to an oscillation in atmospheric mass with centers of action near Iceland and over the subtropical Atlantic from Azores across the Iberian Peninsula (www.Ideo.columbia.edu). Negative NAO index phase is associated with a weakening of both the Icelandic low and Azores high, which acts to decrease the pressure gradient across the North Atlantic. This decreased pressure gradient results in a slackening of the westerlies and is associated with cold, dry weather in Eastern North Atlantic (www.cep.rutgers.edu). Positive NAO index phase is associated with a strengthening of the Icelandic low and Azores high. This results in an increased pressure gradient over the North Atlantic, which causes westerlies to increase in strength and causes increased temperatures and precipitation in Europe (Hurrell 1995).

North Atlantic Oscillation (NAO) was represented by a dataset containing monthly mean sea-level pressure (MSLP) difference between a station on the Azores and one on Iceland. Here data were used for SW Iceland (Reykjavik) and Ponta Delgada (Azores) and NAO time series was the January values (NAO winter; Hurrel 1995). The NAO is described by Rayner *et al*. (2005) and the digital data were obtained from the Joint Institute for the study of the Atmosphere and Ocean at www.jisao.washington.edu/data_sets/nao/nao.ascii. The data taken from the NAO dataset were plotted to present the trends and is shown in Figure 2.9.2. Table 2.9.2 shows the NAO from 1958/1959 fishing season to 1999/2000.

Table 2.9.2 North Atlantic Oscillation (NAO) winter index values by fishing season (Hurrell, 1995)

Fishing Season	NAO
1958/1959	-0.20
1959/1960	-0.84
1960/1961	0.98
1961/1962	-1.30
1962/1963	-1.96
1963/1964	-1.56
1964/1965	-1.57
1965/1966	-0.92
1966/1967	0.70
1967/1968	-0.57
1968/1969	-2.67
1969/1970	-1.03
1970/1971	-0.52
1971/1972	0.19
1972/1973	1.37
1973/1974	0.67
1974/1975	0.89
1975/1976	0.75
1976/1977	-1.17
1977/1978	0.09
1978/1979	-1.23
1979/1980	0.31
1980/1981	1.12
1981/1982	0.44
1982/1983	1.87
1983/1984	0.87
1984/1985	-0.34
1985/1986	0.27
1986/1987	-0.41
1987/1988	0.39
1988/1989	2.77
1989/1990	2.16
1990/1991	0.56
1991/1992	1.79
1992/1993	1.46
1993/1994	1.65
1994/1995	2.16
1995/1996	-2.06
1996/1997	-0.11
1997/1998	0.39
1998/1999	0.93
1999/2000	1.53
2000/2001	Na
2001/2002	Na
2002/2003	Na
2003/2004	Na
2004/2005	Na
2005/2006	Na
2006/2007	Na
2007/2008	Na
2008/2009	Na

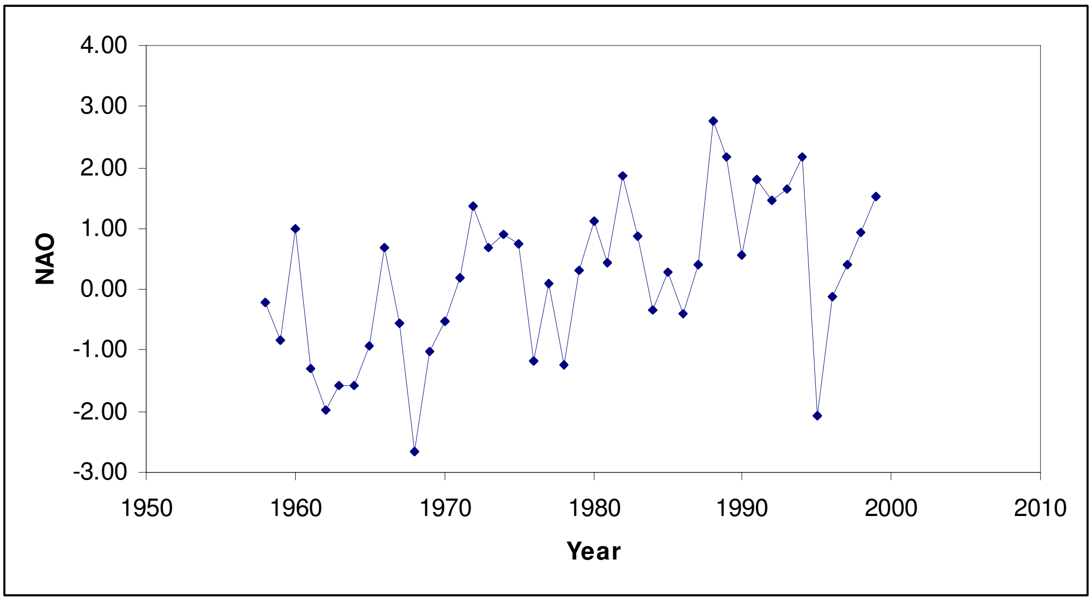


Figure 2.9.2. NAO, Hurrell Index displayed corresponding to fishing season.

2.10 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus*

The monthly mean abundance data of both *Calanus finmarchicus* and *Calanus helgolandicus* for ICES Divisions VIIa, VIIg and VIIj from 1958 to 2006 were obtained from the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) through a licence agreement. The total number of samples per month for each division was also obtained.

The Continuous Plankton Recorder (CPR) device collects plankton continuously from a mean towing depth of 6-7m (Hays & Warner, 1993). The mesh size of the filtering silk is 270µm and the volume of water filtered for 10 nautical mile sample is ~3m³. In the laboratory, 10 nautical mile samples are analysed by CPR analysts using a standardised protocol (Richardson et al, 2005).The monthly mean values provided by SAHFOS from 1958 to 2006 are the average number of organisms (*Calanus finmarchicus* and *Calanus helgolandicus*) in a given month.

For *Calanus finmarchicus* and *Calanus helgolandicus*, the monthly means from 1958 to 2006 for ICES Divisions VIIa, VIIg and VIIj were tabulated and plotted. Tables 2.10.1 to 2.10.3 respectively show the number of samples collected per month by CPR from 1958 to 2006.

Mean abundance (counts) of *Calanus finmarchicus* are shown in Tables 2.10.4 to 2.10.6 for ICES Divisions VIIa, VIIg and VIIj respectively. Mean abundance (counts) of *Calanus helgolandicus* are presented in Tables 2.10.7 to 2.10 .9 for ICES Divisions VIIa, VIIg and VIIj respectively.

Table 2.10.1 Number of samples collected by CPR in ICES Division VIIa from 1958 to 2006

	month	Q2		Q3			Q4			Q1		
year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959												
1959/1960						3						
1960/1961												
1961/1962							2			2		4
1962/1963												1
1963/1964			1									
1964/1965												
1965/1966			1	1							1	
1966/1967												
1967/1968	1					1						
1968/1969	1	1										
1969/1970									1			
1970/1971							8	8	8	8	8	9
1971/1972	8	8	9	8	8	8	10	8	9	9	8	9
1972/1973	8	8	8	8	1	8	8	8	8	9	1	8
1973/1974	8	8	8	8	8	8	9		9	8		
1974/1975	8	8	1		8	8	8	9	1		9	8
1975/1976	9		9	9	9	9	8	8	9	9	8	8
1976/1977	8	9	8	8	8	8	8	8	8	8	8	8
1977/1978	8		8		9	9	8	8	8	8	8	9
1978/1979	8		8	9		9	8	8	8		9	8
1979/1980	8	8	8	8		9				8	8	9
1980/1981	9	9	9	8	9	8	9	6	9	9	9	9
1981/1982	9		9	8	9	9	9	4	9		9	9
1982/1983	9	9	9	8		9	8	8		9	9	10
1983/1984	10	6	9	9	9	9	1	9	9	9	8	9
1984/1985	11		11	9	8	10	9	10	9	11	11	
1985/1986	9	10	10		2	9	9	9		8	13	9
1986/1987	17	5	13	13	8	5	5	13	10		4	6
1987/1988	8	13	6	14	8	13	7	9	8			
1988/1989				3	2	3	3	3	2	5		4
1989/1990	5	7	5	4		13	12	11	7	9		
1990/1991	15	9	14	10	10	8	9	10	16	9	13	7
1991/1992	13	7	8	14	9	12	9	15	9	9	12	8
1992/1993	9	3	12	2	13	12	12	8	11	14	14	12
1993/1994	11	8	14	9		10	14	8	15	12	9	12
1994/1995	12	11	10	19	22	17	17	19	18	15	10	20
1995/1996	27	27	28	21	22	19	13	9	10	8	8	8
1996/1997	8	11	12	8	10	10	8	7	7	11	7	10
1997/1998	16	13	10	9	7		11	10	8	9	12	12
1998/1999	8	14	13	13	8	13	4	12	1	21	13	12
1999/2000	11	15	13	6	13	15	13	11	12	13	12	11
2000/2001	9	13	7	13		11	12	12	11	12		8
2001/2002	17	12	10	11	11	12	11	11	7	11	12	10
2002/2003	10	11	12	8	4	10	10	11	7		10	11
2003/2004	11	11	10	4	8	11	11	11	12	11	7	7
2004/2005	8	4	18	4	9	11	9	11	12	10	9	15
2005/2006	11	12	4	10	10	13	9	6		9	10	10
2006/2007	10	11	9	13	6	9	10	8	9			

Table 2.10.2 Number of samples collected by CPR in ICES Division VIIg from 1958 to 2006.

	Month											
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959	7	12	3								7	6
1959/1960		4			7	15	4	4			9	8
1960/1961	9	4									7	6
1961/1962	7	2					11	4	1	5		4
1962/1963	12	10										7
1963/1964	5	8	8	5					4	4		
1964/1965		7	5	4						4	1	
1965/1966			8	12	12	4			8	11	7	
1966/1967											7	7
1967/1968	7	5	5			8	11	1	4	3		8
1968/1969	7	12	4									
1969/1970		11	4	1			6	11	11	3		
1970/1971	8	8	12	4			6	6	6	7	7	13
1971/1972	13	8	20	6	14	6	6	5		12	7	6
1972/1973	9	6	5	6	5	7		10		14	7	
1973/1974	12	7	7	7		6	9	7	7	7	18	7
1974/1975	6		6	2	3				7		6	13
1975/1976		4	6	7	9	6	9	6	12		7	8
1976/1977	7	6	9	6	9	6	10	7	6		6	2
1977/1978	6	7	6	9	6	8		4	3			2
1978/1979	4	1		3		6		3	2			
1979/1980	4		9	13	4	13	9	14	9		5	
1980/1981	10	8	1	13		14	10	2	9		10	10
1981/1982	1	10	13	14		14	10	10	10	4	13	14
1982/1983	14	9	10	8	17	16	10	13	10	13	4	12
1983/1984	2	10	2	6	8	5	4	14	10	13	6	9
1984/1985	5	11	9	7	17	2	9	3	10	9	3	5
1985/1986	10	19	2	8	8	9	9	19			11	9
1986/1987	8	10	11	12	9	5	13	8	4	8	5	11
1987/1988	9	7	11	7	7	12	13	8	3		7	5
1988/1989	8	7	16	4	5	13	13	9	9	12	6	11
1989/1990	12	14	12	12	13	19	4	10	6	5		8
1990/1991	4	4	12	2	12	5	7	16	7	5	6	8
1991/1992	10	12	12	11	17	5	9	9	4	4	5	5
1992/1993		10		8	3	5	12	8	12	12	13	3
1993/1994	4		5	3		5	4		8	4	5	4
1994/1995	13	5	6	5	9		5	12	6	6	13	12
1995/1996	12	12	11	17	11	11	12	12	5	7	7	
1996/1997		13	7	7	12	14	5	13	5		6	12
1997/1998	17	5	21	12		4	11	5	2	6	11	10
1998/1999	5	19	3	12	7	13	5	3	5	15	11	8
1999/2000	11	4	13	11	12	10	11	13	5	4	5	4
2000/2001		3		4		4	4	3	4	4	4	4
2001/2002	16	8	4	4	4	3	4	4	5	5	8	9
2002/2003	8	8	4	4	4	4	8	9	9		8	8
2003/2004	4	4	4	9		4	4	4	4	4		
2004/2005			16	4	4	4	8	8	7	8	4	13
2005/2006	5	9	5	5	2	4	5		4	9	9	6
2006/2007	6	5	2	9		2	5	6	7			

Table 2.10.3 Number of samples collected by CPR in ICES Division VIIj from 1958 to 2006.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959	6	14	6						2		7	15
1959/1960		6			7	18	11	6			7	8
1960/1961	12	9	4							1	13	6
1961/1962	15	6	5			3	15	6	6	7		6
1962/1963	13	15										4
1963/1964	5	8	9	12		1		1	15	6		
1964/1965	1	13	6	6						5	6	
1965/1966	1		8	14	13	6		1	8	15	9	
1966/1967			1							1	8	9
1967/1968	10	5	6		1	8	14	6	7	12		8
1968/1969	7	14	7		6						2	
1969/1970	4	21	12	10		10	11	22	15	6		
1970/1971	17	9	21	7	6	6		6			6	7
1971/1972	8	15	8	7	8		4	6		14	7	
1972/1973	11		13		12		4	6		9		7
1973/1974	7			13	1	3	7			13	8	16
1974/1975			8	7	8				9			6
1975/1976	3	6		6	6	6	6		11		6	7
1976/1977	6	5	6		6		6				6	6
1977/1978	5		6	6		6		6	6	6	7	6
1978/1979	2	6				9		6	12			6
1979/1980	13			14	6	7		6			4	6
1980/1981			12	12		10		7			4	6
1981/1982			7	6		7	6			6	6	19
1982/1983	5	10	6	7	18	19		14	6	13	13	21
1983/1984	20	13	6	7	13	9	14	14	16	14	15	12
1984/1985		14	20	14	19		16	7	21	26	6	9
1985/1986	7	19	10	3	12	13	7	20	6		12	6
1986/1987	11	13	7	12	5	6	6	4	5	6		7
1987/1988	7	6	6	4	14	6	6	6	7		6	7
1988/1989	6	7	6	4	6	6	6	7	6	6	7	7
1989/1990	7	6	6	6	7	13		7	7	7	5	6
1990/1991		7	6	7	6	7	7	7	7	5	7	7
1991/1992	7	7	7	8	13		6	7				6
1992/1993	2	7	3	6		7	7	6	7	7	7	3
1993/1994	4	11	15	21	11	9	5		8	5		
1994/1995	23	11	11	11	11	12	4	11	19		10	11
1995/1996	11	11	11	12	6	12	11	11		11	11	
1996/1997		10	6	6	6	6		6		6	7	12
1997/1998	11	7	12	11	10		6		8	7	7	
1998/1999	6	11		6	6	7	4			10	6	7
1999/2000	6	9	10	12	6	6	7	6			11	7
2000/2001	9		6	6	6	6	6	1	1	1	6	7
2001/2002	7	7	5	5	5	5					7	6
2002/2003	6	5	5	5	6	6	9	6	6		6	7
2003/2004	11	12		12	6	6	7	5		5		1
2004/2005	6	6	18	6	12	6	11	6	6	6	7	6
2005/2006	12	12	6	11	5	5		6	12	8	10	9
2006/2007	11	6	5			1	1	6				

Table 2.10.4 Mean abundance of *Calanus finmarchicus* in ICES Division VIIa per fishing season.

	month	Q2		Q3			Q4			Q1		
year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959												
1959/1960						0.0						
1960/1961												
1961/1962							0.0			0.0		0.0
1962/1963												0.0
1963/1964			0.0									
1964/1965												
1965/1966			0.0	0.0							1.0	
1966/1967												
1967/1968	0.0					0.0						
1968/1969	0.0	6.0										
1969/1970									0.0			
1970/1971							0.0	0.13	0.0	0.0	0.0	0.2
1971/1972	2.9	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.8	0.0	0.0	0.2
1972/1973	2.9	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.8	0.0	0.0	0.0
1973/1974	0.0	0.5	0.4	0.8	0.0	1.1	0.1		3.3	0.0		
1974/1975	0.0	0.0	0.0		0.0	0.0	0.0	0.2	0.0		0.0	0.1
1975/1976	0.0		0.0	0.9	0.0	0.9	0.5	0.1	0.9	0.0	0.0	0.0
1976/1977	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.1	0.0	0.0	0.0	0.3
1977/1978	0.0		0.0		0.0	0.7	0.8	0.0	0.0	0.0	0.0	0.1
1978/1979	0.0		0.0	0.1		0.1	0.0	0.0	0.0		0.0	0.0
1979/1980	0.0	0.8	0.0	0.1		1.0				0.0	0.0	0.0
1980/1981	0.1	1.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
1981/1982	0.0		0.1	0.9	0.1	0.2	0.0	0.0	0.2		0.1	0.0
1982/1983	0.2	1.4	2.7	0.3		0.8	1.8	0.0		0.0	0.1	0.0
1983/1984	0.1	0.3	0.0	0.4	0.2	1.2	0.0	0.1	0.2	0.1	0.0	0.0
1984/1985	0.0		0.0	0.7	0.0	0.8	0.1	0.0	0.1	0.0	0.0	
1985/1986	1.9	0.0	1.7		0.0	4.4	0.7	0.3		0.0	0.0	0.0
1986/1987	0.6	0.0	0.1	0.0	0.0	0.0	0.2	0.2	0.4		0.0	0.0
1987/1988	0.5	0.0	0.3	0.1	1.1	0.5	0.3	0.1	0.6			
1988/1989				0.0	0.0	0.0	0.0	6.0	1.0	0.4		0.0
1989/1990	0.0	0.0	0.0	0.0		0.1	0.0	0.2	0.0	0.0		
1990/1991	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.3	0.0
1991/1992	0.2	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
1992/1993	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.1	0.0	0.0	0.1
1993/1994	0.0	0.0	0.0	0.0		0.1	0.1	0.0	1.5	0.0	0.1	0.0
1994/1995	0.2	0.0	0.1	0.0	0.6	1.1	0.4	0.7	0.1	0.1	0.0	0.1
1995/1996	0.2	0.0	0.8	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996/1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997/1998	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
1998/1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999/2000	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2000/2001	0.1	0.0	0.0	0.0		0.0	0.0	1.0	0.5	0.9		0.0
2001/2002	1.2	0.5	0.3	0.1	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
2002/2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9		0.1	0.0
2003/2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
2005/2006	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.7	0.0	0.0
2006/2007	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0			

Table 2.10.5 Mean abundance of *Calanus finmarchicus* in ICES Division VIIg per fishing season.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959	5.1	50.0	36.3								1.7	0.2
1959/1960		8.0			2.0	0.4	0.0	0.0			0.0	0.3
1960/1961	0.7	0.0									0.0	0.0
1961/1962	1.1	1					1.9	0.0	0.0	0.6		0.3
1962/1963	0.0	0.8										0.3
1963/1964	0.0	1.3	0.0	0.0					0.0	0.3		
1964/1965		1.1	1.4	1.5						0.3	1.0	
1965/1966			1.0	0.6	0.0	0.0			10.5	0.5	6.4	
1966/1967											0.0	0.0
1967/1968	0.4	0.0	1.6			0.0	0.0	0.0	1.0	0.0		0.3
1968/1969	0.0	4.8	0.0									
1969/1970		2.3	0.3	0.0			0.0	0.1	0.0	0.3		
1970/1971	0.0	0.0	0.1	0.0			0.0	7.8	0.0	0.0	0.0	0.3
1971/1972	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0		0.5	0.0	0.2
1972/1973	0.0	0.0	1.4	0.0	0.0	0.0		5.5		0.1	0.0	
1973/1974	0.8	0.9	0.0	0.1		0.2	0.0	0.0	0.0	0.0	0.2	0.0
1974/1975	0.8		0.2	0.0	0.0				0.0		0.0	0.0
1975/1976		0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0		0.0	0.0
1976/1977	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0
1977/1978	0.0	0.0	0.0	0.0	0.0	0.0		0.5	0.0			0.0
1978/1979	0.0	0.0		0.0		4.8		1.0	1.5			
1979/1980	39.5		0.0	0.0	0.0	0.1	0.0	2.9	0.0		0.0	
1980/1981	0.0	0.0	0.0	0.0		5.4	0.2	26.0	0.0		0.0	0.2
1981/1982	0.0	4.1	2.7	0.2		0.1	0.3	0.0	0.2	2.0	3.9	0.0
1982/1983	16.5	12.1	0.0	0.0	0.1	1.6	6.7	0.5	0.3	0.0	0.0	0.5
1983/1984	75.0	8.9	8.5	0.0	0.1	0.0	0.0	0.3	0.2	0.0	0.3	0.1
1984/1985	0.0	5.4	0.9	0.0	0.0	0.5	0.0	0.0	0.2	2.4	0.0	0.0
1985/1986	15.9	5.3	0.0	2.5	0.0	0.1	1.9	3.7			2.5	0.3
1986/1987	0.5	2.9	0.3	1.5	1.4	0.2	0.5	0.9	0.3	0.8	0.0	1.1
1987/1988	15.2	16.0	10.4	1.1	0.4	0.3	1.3	3.5	0.0		0.0	0.2
1988/1989	9.4	6.0	0.2	0.0	1.8	1.0	2.1	4.9	1.7	0.2	0.7	2.7
1989/1990	1.7	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.8	1.6		0.1
1990/1991	1.0	1.5	0.6	0.0	0.4	0.0	0.0	0.5	1.3	1.0	0.3	3.6
1991/1992	10.5	22.0	0.6	0.7	0.0	0.0	0.1	0.4	0.0	0.0	0.6	0.8
1992/1993		2.3		0.0	0.0	2.6	0.9	0.0	0.2	0.2	5.8	0.0
1993/1994	1.0		0.2	0.0		0.4	0.5		6.1	0.0	0.4	0.0
1994/1995	0.8	3.4	0.0	0.0	0.0		0.0	0.0	0.5	1.0	0.7	0.9
1995/1996	1.3	0.0	7.4	0.4	1.1	0.0	0.0	0.1	0.0	0.3	0.0	
1996/1997		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0		3.3	0.0
1997/1998	0.4	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	5.2	0.2
1998/1999	0.2	0.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	2.1
1999/2000	0.8	0.0	0.1	0.0	0.0	0.0	1.5	0.0	0.2	0.0	0.0	0.0
2000/2001		0.0		0.0		1.5	0.0	7.7	9.8	8.0	2.3	1.3
2001/2002	13.2	43.1	0.0	0.5	0.0	0.0	0.0	0.0	0.2	0.0	0.5	0.0
2002/2003	18.4	11.6	0.0	0.0	0.0	0.0	0.0	1.3	0.8		3.6	0.4
2003/2004	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0		
2004/2005			1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2
2005/2006	2.8	1.3	0.0	0.0	0.0	0.0	0.0		0.8	4.7	0.0	1.7
2006/2007	0.0	0.0	0.0	0.0		0.0	0.0	0.5	0.0			

Table 2.10.6 Mean abundance of *Calanus finmarchicus* in ICES Division VIIj per fishing season.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959	0.3	9.5	9.3						0.0		0.9	0.0
1959/1960		18.5			0.0	0.0	0.0	0.0			0.0	0.0
1960/1961	0.9	0.0	0.0							0.0	0.2	0.0
1961/1962	1.1	1.0	0.8			0.0	0.1	3.2	0.5	0.1		0.2
1962/1963	0.2	0.5										0.0
1963/1964	0.2	0.5	1.0	1.8		0.0		0.0	3.1	0.0		
1964/1965	0.0	0.7	1.2	0.5						1.0	0.0	
1965/1966	2.0		0.1	0.7	0.0	2.0		0.0	1.9	0.5	0.8	
1966/1967			0.0							0.0	0.0	0.2
1967/1968	0.2	0.0	0.0		0.0	0.0	0.1	0.0	0.1	0.0		0.0
1968/1969	0.0	6.3	27.6		1.0						0.0	
1969/1970	0.8	2.6	0.0	1.8		0.0	0.0	0.0	0.0	0.0		
1970/1971	0.2	0.9	1.0	0.0	0.0	0.0		0.0			0.0	1.7
1971/1972	0.0	1.9	2.1	0.1	0.0		1.0	0.0		1.9	0.1	
1972/1973	0.1		0.8		0.0		4.3	0.0		0.0		0.0
1973/1974	2.7			0.0	0.0	0.0	0.9			0.5	0.0	1.2
1974/1975			0.0	0.0	0.0				0.1			0.2
1975/1976	2.3	0.0		0.0	0.0	0.2	1.2		0.0		0.0	0.0
1976/1977	0.0	0.0	0.0		0.0		0.0				0.0	0.0
1977/1978	0.2		9.2	0.0		0.0		0.5	0.0	0.0	0.0	0.0
1978/1979	0.0	0.0				9.1		7.5	1.2			0.7
1979/1980	25.9			0.0	1.5	8.1		3.8			0.0	1.5
1980/1981			4.5	4.0		2.4		2.0			4.5	27.7
1981/1982			24.6	0.0		0.9	7.8			8.8	0.3	0.3
1982/1983	10.4	2.8	0.0	0.0	0.0	0.0		0.1	0.3	0.0	0.9	0.0
1983/1984	46.2	6.5	2.8	0.1	0.0	0.2	0.8	0.1	0.1	0.0	0.1	0.8
1984/1985		13.4	1.5	0.1	0.0		0.0	0.0	0.8	0.6	0.0	0.1
1985/1986	4.7	14.3	2.4	0.0	0.3	10.4	0.0	3.5	0.0		1.7	0.2
1986/1987	8.6	3.5	12.3	0.8	1.8	2.8	2.8	0.0	0.2	0.0		0.6
1987/1988	2.3	6.8	0.7	0.0	0.0	0.0	0.0	1.0	0.0		0.0	0.0
1988/1989	42.0	1.9	0.2	1.5	0.0	4.3	0.3	0.0	0.2	0.2	0.1	0.9
1989/1990	4.1	0.2	0.3	0.0	0.0	0.0		0.0	0.0	0.6	0.0	0.2
1990/1991		4.4	1.0	0.1	0.0	0.0	0.6	0.1	0.3	0.2	0.0	5.6
1991/1992	4.6	30.6	3.4	0.4	0.2		0.0	0.0				0.2
1992/1993	1.5	2.7	7.7	0.0		0.0	1.0	1.0	0.0	0.4	1.1	0.0
1993/1994	0.8	0.8	3.3	0.0	0.0	0.0	0.2		0.0	0.0		
1994/1995	0.6	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.1		1.7	0.1
1995/1996	0.3	0.7	2.3	0.0	0.5	0.0	0.0	0.0		0.1	0.0	
1996/1997		0.8	0.3	0.0	0.0	0.0		0.0		7.0	0.3	0.0
1997/1998	11.5	1.1	0.0	0.1	0.0		0.0		0.0	0.0	0.3	
1998/1999	0.0	3.6		0.0	0.0	0.0	0.0			0.6	0.0	5.9
1999/2000	0.2	24.0	0.0	4.4	0.0	0.0	0.0	0.0			0.0	0.0
2000/2001	1.7		0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	1.5	0.0
2001/2002	32.4	32.9	0.0	0.0	0.0	0.0					0.1	0.2
2002/2003	2.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0		3.0	0.9
2003/2004	0.5	0.0		0.0	0.0	0.0	0.0	0.0		0.0		0.0
2004/2005	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.0	4.8
2005/2006	14.3	0.5	0.0	0.0	0.0	0.0		0.0	0.0	0.3	0.1	0.9
2006/2007	0.0	0.0	0.0			0.0	0.0	0.0				

Table 2.10.7 Mean abundance of *Calanus helgolandicus* in ICES Division VIIa per fishing season.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959												
1959/1960						29.0						
1960/1961												
1961/1962							3.0			2.5		0.3
1962/1963												0.0
1963/1964			17.0									
1964/1965												
1965/1966			0.0	0.0							35.0	
1966/1967												
1967/1968	6.0					35.0						
1968/1969	17.0	17.0										
1969/1970									75.0			
1970/1971							0.6	0.3	0.0	0.0	0.6	0.2
1971/1972	0.0	0.0	0.3	0.9	3.1	4.3	2.3	2.0	0.1	0.6	0.0	0.0
1972/1973	0.0	0.0	0.9	2.3	6.0	3.0	1.9	0.0	0.1	0.7	0.0	0.1
1973/1974	0.4	0.3	0.0	0.3	6.9	23.3	1.7		0.4	0.0		
1974/1975	0.0	0.1	2.0		0.1	0.3	1.8	0.6	0.0		0.0	0.0
1975/1976	0.0		0.0	0.3	1.9	4.8	0.3	0.1	3.1	3.1	0.4	0.1
1976/1977	0.0	0.6	0.8	0.4	0.0	1.6	0.4	0.1	0.4	0.1	1.1	0.0
1977/1978	0.0		0.1		3.0	0.2	0.1	1.0	0.3	0.0	0.0	0.2
1978/1979	0.0		0.4	0.1		4.1	2.8	3.5	0.1		0.0	0.1
1979/1980	0.0	0.6	0.0	0.0		0.3				0.0	0.1	0.1
1980/1981	0.0	2.2	0.7	0.0	0.0	0.0	0.0	0.5	0.2	0.4	0.2	0.0
1981/1982	0.4		0.0	10.9	2.0	0.6	0.8	0.3	0.0		0.1	0.1
1982/1983	0.8	2.4	13.1	0.5		2.3	1.8	0.6		0.0	0.3	0.4
1983/1984	2.4	2.5	1.9	3.7	5.9	8.0	3.0	1.1	0.3	0.7	0.1	0.0
1984/1985	2.0		1.0	1.3	0.9	24.3	0.9	2.4	0.7	1.5	0.3	
1985/1986	3.9	0.3	3.6		3.0	17.7	9.7	3.1		0.0	1.5	0.0
1986/1987	3.1	0.0	1.2	0.5	0.1	2.4	0.0	0.3	0.2		0.0	0.0
1987/1988	0.0	0.2	0.5	0.1	1.1	1.1	5.9	0.0	0.9			
1988/1989				14.0	8.5	2.7	6.7	13.3	1.0	3.2		1.0
1989/1990	0.0	2.0	0.0	0.0		4.5	1.7	3.4	0.0	1.9		
1990/1991	0.2	0.0	0.4	0.0	0.8	0.0	0.7	2.2	0.1	0.0	0.2	1.1
1991/1992	3.3	5.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.1	0.0
1992/1993	0.0	0.0	0.2	0.0	2.8	0.5	1.1	0.0	0.5	0.1	0.1	0.1
1993/1994	0.3	0.0	0.0	0.0		0.2	0.8	0.1	4.2	0.3	0.4	0.2
1994/1995	0.1	0.1	0.0	1.7	4.3	18.9	25.2	4.3	1.7	0.2	0.1	0.4
1995/1996	1.3	0.5	3.5	2.9	1.7	2.8	7.2	1.2	10.9	0.0	0.8	0.0
1996/1997	0.1	1.3	0.1	0.3	3.8	0.1	0.1	0.4	0.6	0.2	0.0	0.2
1997/1998	0.1	4.6	0.3	0.0	0.0		0.1	0.0	0.0	0.0	0.4	0.0
1998/1999	0.1	0.1	0.1	0.2	0.0	0.5	0.0	0.0	2.0	0.1	0.0	0.0
1999/2000	0.4	0.6	0.1	1.2	0.0	1.7	0.5	0.4	0.2	0.0	0.0	0.1
2000/2001	2.0	0.5	0.0	0.7		0.1	1.7	7.8	7.6	3.2		0.0
2001/2002	5.9	2.0	0.8	1.1	0.5	0.3	1.8	5.6	1.4	0.6	0.8	0.0
2002/2003	0.6	5.5	0.7	0.1	0.0	0.3	1.0	0.7	3.7		1.2	1.7
2003/2004	2.5	0.2	2.6	2.8	0.9	3.5	0.6	0.8	2.5	1.8	0.0	0.0
2004/2005	0.0	0.0	1.6	0.0	1.2	4.5	1.8	0.0	0.1	1.3	0.0	0.5
2005/2006	3.6	0.0	0.0	0.5	2.2	8.6	0.0	0.0		6.4	0.0	1.1
2006/2007	2.6	0.7	0.1	1.2	4.8	8.8	0.9	0.9	1.8			

Table 2.10.8 Mean abundance of *Calanus helgolandicus* in ICES Division VIIg per fishing season.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959	10.1	113.5	117.0								3.0	0.2
1959/1960		11.5			39.9	38.5	2.0	27.8			0.0	0.3
1960/1961	5.9	47.8									13.9	4.8
1961/1962	18.6	11.5					22.6	6.0	6.0	0.8		0.0
1962/1963	0.5	7.4										0.1
1963/1964	0.2	49.5	17.8	9.0					0.75	0.3		
1964/1965		7.4	4.0	6.3						4.5	2.0	
1965/1966			54.8	23.5	38.5	1.8			22.4	6.8	21.6	
1966/1967											0.1	0.7
1967/1968	7.9	40.8	12.6			53.1	22.3	6.0	8.8	4.3		1.6
1968/1969	11.6	56.2	31.5									
1969/1970		58.4	7.8	17.0			5.0	1.0	9.5	0.7		
1970/1971	3.1	73.6	82.6	14.5			61.7	1.3	12.5	0.0	4.0	0.5
1971/1972	0.4	0.8	9.6	0.3	22.4	24.2	12.7	16.2		1.8	2.4	1.0
1972/1973	7.0	24.2	72.4	4.5	6.6	16.0		20.9		6.8	6.3	
1973/1974	4.7	3.6	6.1	7.6		22.2	6.8	3.0	0.4	0.0	3.4	6.0
1974/1975	17.0		41.7	117.5	12.0				4.3		1.0	0.1
1975/1976		45.0	13.0	4.0	12.4	44.2	25.2	52.0	6.4		0.3	0.9
1976/1977	7.1	0.7	34.2	3.8	20.9	16.3	11.8	23.4	0.5		0.7	0.0
1977/1978	7.8	4.7	6.7	6.2	5.3	12.6		2.8	0.0			1.5
1978/1979	0.5	17.0		9.7		42.3		0.0	1.0			
1979/1980	8.8		27.2	104.8	23.8	80.2	32.2	22.4	3.7		1.4	
1980/1981	0.5	11.3	6.0	4.0		11.2	10.8	3.0	1.9		0.3	1.5
1981/1982	1.0	15.5	28.6	3.2		16.6	17.8	9.2	12.9	7.8	4.7	0.5
1982/1983	17.2	27.4	6.3	30.5	16.0	19.5	47.4	15.4	1.8	0.6	0.0	0.8
1983/1984	20.5	5.0	26.0	10.5	1.8	2.4	10.0	2.8	1.8	1.1	1.8	1.6
1984/1985	6.6	17.1	22.1	5.1	2.7	9.5	38.8	12.0	5.8	4.8	2.0	0.2
1985/1986	68.9	48.8	26.0	49.4	4.0	7.9	16.6	14.9			7.2	0.2
1986/1987	48.9	8.9	35.7	51.5	21.3	4.2	10.6	19.8	2.5	2.0	2.8	2.5
1987/1988	16.8	25.7	11.6	4.4	29.1	5.8	44.4	5.6	0.7		2.4	1.4
1988/1989	8.6	26.9	5.3	4.5	16.2	7.9	12.2	18.0	3.1	0.8	1.0	2.0
1989/1990	3.4	2.1	7.3	3.3	2.5	27.5	11.5	11.1	3.8	2.2		1.1
1990/1991	6.5	1.5	11.1	4.5	13.4	20.0	10.3	7.4	3.9	3.2	4.5	4.3
1991/1992	9.1	18.7	12.3	7.0	1.6	10.4	27.0	7.2	0.0	0.8	3.2	2.8
1992/1993		2.5		18.9	7.3	12.8	10.3	15.0	1.7	2.7	19.5	0.7
1993/1994	3.8		2.0	9.7		30.0	5.3		15.1	1.8	0.8	0.8
1994/1995	2.5	30.4	2.3	38.2	14.9		32.2	26.9	6.0	15.7	11.8	4.4
1995/1996	45.8	138.3	94.5	32.1	22.9	18.3	27.7	21.8	33.6	2.3	0.0	
1996/1997		84.5	40.7	20.3	28.4	11.9	23.4	4.8	23.6		7.8	7.0
1997/1998	23.2	39.4	13.5	21.9		27.0	15.6	3.8	11.5	0.0	9.3	0.4
1998/1999	11.8	5.8	2.0	11.1	6.0	11.5	1.8	6.0	3.4	1.4	1.4	10.3
1999/2000	11.6	0.0	6.3	18.5	14.7	46.3	21.3	48.5	2.4	1.3	1.4	3.8
2000/2001		11.7		37.8		11.8	11.5	48.3	4.3	23.3	28.8	2.0
2001/2002	22.4	123.9	4.0	0.5	4.8	23.0	3.3	7.3	10.4	2.2	4.4	0.9
2002/2003	75.8	65.4	29.8	1.8	2.8	1.5	18.4	13.1	18.6		24.4	7.3
2003/2004	5.3	11.5	117.5	47.6		6.5	30.5	6.5	10.8	10.0		
2004/2005			41.5	11.0	35.0	2.0	63.1	1.4	25.3	11.5	1.5	10.2
2005/2006	10.2	7.0	3.4	7.0	1.0	2.5	0.8		16.0	31.0	7.6	4.3
2006/2007	8.7	21.0	1.0	11.7		1.5	0.8	23.5	7.0			

Table 2.10.9 Mean abundance of *Calanus helgolandicus* in ICES Division VIIj per fishing season.

	Month	Q2		Q3			Q4			Q1		
Year	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1958/1959	1.5	60.4	27.8						0.0		0.6	0.1
1959/1960		21.2			0.3	7.1	5.6	7.5			0.0	7.1
1960/1961	49.3	19.0	18.8							1.0	14.5	2.8
1961/1962	8.3	46.0	7.0			0.7	13.4	14.5	2.5	2.4		1.2
1962/1963	0.5	30.7										0.0
1963/1964	1.0	80.1	31.4	9.7		0.0		0.0	2.3	0.2		
1964/1965	0.0	8.2	15.7	5.0						1.4	1.2	
1965/1966	1.0		28.5	10.8	6.8	30.3		0.0	5.9	3.7	0.6	
1966/1967			2.0							0.0	0.1	4.8
1967/1968	19.2	59.0	45.5		3.0	14.8	4.7	3.8	1.0	1.0		0.0
1968/1969	2.9	46.2	293.9		63.8						0.0	
1969/1970	5.3	124.4	11.9	23.0		0.0	1.0	1.4	1.5	0.3		
1970/1971	1.1	30.2	37.3	15.9	4.2	0.7		0.3			0.0	1.4
1971/1972	0.0	9.5	17.9	0.1	14.4		1.0	4.7		0.4	8.6	
1972/1973	2.4		53.5		3.7		14.5	4.7		0.1		0.1
1973/1974	50.4			16.1	0.0	2.0	13.1			0.3	0.4	2.0
1974/1975			28.3	20.4	1.0				2.0			0.2
1975/1976	0.0	36.3		20.7	13.0	8.0	0.0		0.3		0.0	0.0
1976/1977	4.2	9.4	7.3		6.8		1.5				0.5	0.0
1977/1978	48.2		56.8	20.2		35.0		2.7	5.2	0.3	0.4	1.3
1978/1979	0.0	40.5				2.1		10.3	2.7			2.2
1979/1980	8.5			108.7	43.2	23.9		14.8			1.5	0.7
1980/1981			54.8	31.2		8.2		0.3			0.0	11.7
1981/1982			70.7	30.8		166.7	29.3			9.7	0.0	1.1
1982/1983	16.2	28.5	11.5	12.3	20.2	4.6		4.2	0.7	1.3	0.5	2.3
1983/1984	34.5	5.2	62.2	31.4	0.6	5.8	7.6	1.1	0.8	1.1	0.2	1.3
1984/1985		34.4	10.7	3.9	15.4		8.6	0.6	13.6	1.4	2.3	1.8
1985/1986	21.9	42.1	10.3	15.7	8.3	7.0	1.4	7.5	2.0		1.9	0.0
1986/1987	15.5	5.0	20.6	8.8	9.8	4.3	9.2	0.5	0.0	0.3		1.4
1987/1988	2.7	48.7	7.8	0.0	9.6	1.7	4.0	1.8	0.0		2.2	1.6
1988/1989	12.2	5.6	4.3	3.0	1.8	12.5	1.3	0.1	0.0	0.0	0.9	2.1
1989/1990	2.7	0.7	8.2	1.3	9.1	7.1		0.0	0.1	1.4	0.0	0.8
1990/1991		11.1	24.2	4.0	0.3	0.0	1.1	3.3	1.1	0.0	0.0	2.6
1991/1992	6.1	63.9	6.7	7.5	3.5		11.0	5.4				0.2
1992/1993	6.0	9.7	36.3	25.3		0.1	5.0	13.7	0.0	0.3	2.9	0.0
1993/1994	2.5	3.0	2.4	1.7	0.5	0.3	2.0		1.0	0.2		
1994/1995	2.4	22.8	9.2	86.5	18.7	12.2	18.0	10.5	1.1		4.5	1.5
1995/1996	7.6	79.4	26.4	6.9	2.2	0.8	4.5	1.8		0.1	0.1	
1996/1997		76.4	53.5	12.0	12.5	0.5		0.2		0.2	3.7	2.3
1997/1998	25.9	28.9	7.4	5.4	1.0		0.0		2.3	0.0	3.7	
1998/1999	3.3	23.5		1.7	1.3	6.3	5.8			0.5	0.2	24.9
1999/2000	1.8	25.4	18.6	22.3	131.2	1.3	1.1	18.5			0.6	5.3
2000/2001	11.0		40.3	21.7	18.3	0.0	0.2	0.0	0.0	0.0	13.7	0.3
2001/2002	15.6	16.4	38.8	23.2	16.2	0.0					2.3	2.0
2002/2003	17.3	104.6	10.4	25.8	2.8	0.0	29.0	1.2	10.7		1.2	4.1
2003/2004	41.4	17.3		57.3	71.8	0.3	0.0	0.6		3.4		1.0
2004/2005	5.8	10.5	32.8	4.5	2.8	3.8	0.3	3.8	1.2	3.2	0.1	17.3
2005/2006	53.4	84.7	21.0	10.5	2.6	0.2		0.3	3.3	6.8	0.6	4.0
2006/2007	3.9	6.0	26.6			0.0	0.0	5.8				

2.11 Environmental data analysis

Correlations

Product Moment Correlation (Fowler *et al*, 1998) was employed to test the strength of association between environmental and biological variables. This was calculated as follows:

$R = n\sum xy - \sum x\sum y \ / \sqrt{}[n\sum x^2 – (\sum x)^2][n\sum y^2 - (\sum y)^2\}$

Where x = environmental variable

Y = biological variable

R = correlation coefficient

Significance levels were tested using the table of the product moment correlation values (Fowler *et al*., 1998).

2.12 Stock assessment data

The data available on stock status were taken from the final accepted assessment conducted in 2009 (Anon, 2009). The data presented are as follows:

- Spawning stock biomass (SSB) is the total weight of all sexually mature fish in the population. The size of SSB for a stock depends on abundance of year classes, the exploitation pattern, the rate of growth and natural mortality rates, the onset of sexual maturity and environmental conditions.
- Recruitment is the number of fish added to the exploitable stock each year into the fishing area.
- Fishing Mortality (F) is the death rate in a stock caused by fishing.

3. RESULTS

3.1 Data available

The following biological data were available to this project: length, weight, sex, maturity, age estimate and vertebrae counts. Table 3.1.1 shows the years for which these data were available. It can be seen that certain parameters such as vertebral counts and weight were not recorded in all years. Although vertebrae counts were recorded from 1960 - 1993, only a small number of samples were used and the numbers vary from year to year.

Table 3.1.1. The parameters collected in the sampling scheme and the years in which these were taken.

Year	Length (cm)	Weight (g)	Sex	Maturity (appendix II)	Vertebral count	Age (winter rings)
1959 - 1975	present	absent	present	present	present	present
1975 - 1993	present	present	present	present	present	present
1993 - 2007	present	present	present	present	absent	present

Table 3.1.2 shows the number of samples collected by fishing season. It can be seen that sampling intensity increased from very low numbers in 1959 - 1961 to between 18 and 48 samples per season for the rest of the 1960s. Sampling intensity was slightly lower in the 1970s but increased again from the early 1980s with over 100 samples per season in the late 1980s and early 1990s. In recent years the number of samples was between 34 and 61 per season. It can be seen that the numbers of measured fish and aged fish were similar in the early 1960s. From 1973 onwards, the numbers of measured fish increased compared to the numbers of aged fish of the same year. The numbers of measured fish dramatically increased in 1982/1983 with 8808 fish measured and approximately 25% of those fish were aged. This level of sampling

continued thereafter with between approximately 20% and 30% of the measured fish being aged from year to year.

Table 3.1.3 shows the number of samples collected in each ICES Division in the Celtic Sea. It can be seen that samples were collected mainly in VIIaS until 1966/1967. In the 70s VIIaS was still the main area from which samples were collected and there were very few samples collected in VIIj until 1979/1980. It can be seen that there were no samples collected in VIIaS in 1987 – 1989 and that in recent years, there have been very few samples collected in VIIj. These differences are, partly, due to fishing effort. VIIaS has always been a centre of herring fishing, while effort in VIIj has been more sporadic.

Table 3.1.2 The numbers of samples collected each fishing season, since 1959.

Year	Number of Samples	Number aged	Number measured
1959/1960	1	99	150
1960/1961	2	159	168
1961/1962	1	50	50
1962/1963	18	1742	1746
1963/1964	47	6025	6025
1964/1965	40	4791	4802
1965/1966	26	2720	2726
1966/1967	34	3707	3836
1967/1968	39	4287	4299
1968/1969	35	3353	3353
1969/1970	48	3610	3626
1970/1971	44	2830	2886
1971/1972	26	2191	2241
1972/1973	25	2188	3225
1973/1974	17	1152	3776
1974/1975	19	1483	4418
1975/1976	26	1938	3288
1976/1977	12	762	1622
1977/1978	11	645	2468
1978/1979	25	1191	3866
1979/1980	46	2195	6552
1980/1981	37	1685	4795
1981/1982	30	1411	4547
1982/1983	45	2174	8808
1983/1984	59	1937	10595
1984/1985	70	2481	8767
1985/1986	40	1611	7458
1986/1987	52	1771	4999
1987/1988	79	2818	13189
1988/1989	117	3860	19266
1989/1990	121	3368	18879
1990/1991	86	2178	13411
1991/1992	109	2029	14907
1992/1993	86	2234	14414
1993/1994	61	1613	10550
1994/1995	74	1812	13126
1995/1996	73	2032	10710
1996/1997	82	2971	14740
1997/1998	83	3381	12483
1998/1999	58	2545	10982
1999/2000	66	1742	12235
2000/2001	39	1251	8098
2001/2002	123	2587	18898
2002/2003	34	1339	5645
2003/2004	43	2133	8180
2004/2005	42	2934	4712
2005/2006	42	2330	5416
2006/2007	61	3040	9437
Total	2354	108535	354698

Table 3.1.3 The number of samples collected in the fishing season in each ICES Divisions in the Celtic Sea. Note that fish aged are a subset of those measured, according to the sampling protocol.

Year	VIIaS Number of Samples	Number Aged	Number Measured	VIIg Number of Samples	Number Aged	Number Measured	VIIj Number of Samples	Number Aged	Number Measured
1959/1960	0	0	0	1	150	99	0	0	0
1960/1961	2	159	168	0	0	0	0	0	0
1961/1962	1	50	50	0	0	0	0	0	0
1962/1963	18	1742	1746	0	0	0	0	0	0
1963/1964	47	6025	6025	0	0	0	0	0	0
1964/1965	40	4791	4802	0	0	0	0	0	0
1965/1966	23	2383	2389	3	337	337	0	0	0
1966/1967	21	2181	2306	10	1076	1080	3	450	450
1967/1968	21	2237	2242	16	1800	1807	2	250	250
1968/1969	19	1924	1924	15	1373	1373	1	56	56
1969/1970	33	2297	2311	11	958	960	4	355	355
1970/1971	36	2215	2215	3	268	268	5	347	403
1971/1972	20	1674	1724	6	517	517	0	0	0
1972/1973	21	1729	2765	4	459	460	0	0	0
1973/1974	16	1080	3704	1	72	72	0	0	0
1974/1975	15	1077	3570	4	406	848	0	0	0
1975/1976	16	1117	2014	8	722	1020	2	99	254
1976/1977	6	442	858	4	245	286	2	75	478
1977/1978	6	396	818	1	50	206	4	199	1444
1978/1979	11	514	2004	6	308	514	8	369	1348
1979/1980	23	1071	3104	6	287	1033	17	837	2415
1980/1981	14	586	1664	19	914	2306	4	185	825
1981/1982	11	539	1383	11	496	1204	8	376	1960
1982/1983	18	848	3735	14	694	2194	13	632	2879
1983/1984	34	1194	7369	8	299	1500	17	444	1726
1984/1985	35	1238	4666	13	544	1820	22	699	2281
1985/1986	18	644	2318	17	718	4368	5	249	772
1986/1987	2	50	160	32	1085	3273	18	636	1566
1987/1988	0	0	0	74	2570	12543	5	248	646
1988/1989	0	0	0	104	3272	17426	13	588	1840
1989/1990	13	508	2320	75	1617	11104	33	1243	5455
1990/1991	34	665	4410	23	757	4598	29	855	4837
1991/1992	71	741	8322	25	746	3699	13	542	2886
1992/1993	60	1288	8827	13	398	2833	13	548	2754
1993/1994	39	675	6545	10	394	2069	12	544	1936
1994/1995	38	471	5596	26	992	5549	10	349	1981
1995/1996	43	913	5823	14	447	1784	16	672	3103
1996/1997	32	1048	4691	29	1001	4553	21	922	5496
1997/1998	40	1536	5534	15	684	2459	29	1161	4435
1998/1999	31	1041	3888	16	740	4431	11	764	2663
1999/2000	25	508	3904	28	787	5302	13	447	3029
2000/2001	11	199	2493	17	557	3758	11	495	1847
2001/2002	36	579	5845	56	1261	8747	31	747	4306
2002/2003	18	552	2214	8	319	1571	8	468	1860
2003/2004	21	626	4717	19	1225	2985	3	282	478
2004/2005	31	2301	3462	8	391	830	3	242	420
2005/2006	23	1076	2406	15	1030	2154	4	224	856
2006/2007	48	2119	5918	11	799	3121	2	122	398
Total	1141	57049	154949	799	33765	129061	415	17721	70688

3.2 Data input, storage and extraction

The data entry stage of this project was very time consuming, and took several years to complete and check. The data were entered directly onto the Stockman database from the hand written data sheets with 2717 samples being entered. A tally of numbers of fish aged per length had to be calculated for each sample and the total numbers of measured fish for each sample had to be checked before the samples were inputted. In the 1960s and the early 1970s the fish were measured to the nearest 0.1 cm and in order to be consistent with the remainder of the data, these years had to be rounded down to the nearest 0.5 cm.

It is thought that all biological records of Irish sampling have been inputted, except for the first three years of the dataset where the sample numbers were very low. Foreign sampling of the catches from this stock was not included and it is not known where these data records are stored or if they still exist. However foreign catches have not been significant since the 1970s.

The results presented in Section 3.5 and Section 3.6 is based on the "summaries" that are raised to the standard landings figure of 1,000 tonnes. This standard figure was chosen because the true landings by quarter and by year were not consistently known. However, for the purpose of examining biological characteristics of the stock, it was irrelevant what tonnage was used to raise the data, as the relative proportions at length, weight, age and maturity are the same This was confirmed by comparing data taken from ICES Division VIIa South Q4 2006 using 1,000 tonnes for one extraction and using official landings (1,754t) for another extraction.

3.3 Estimation of age

The time series of age data available for this herring stock are considered to be of a very high quality. This is because the estimates were produced by only six readers. Expertise in reading and interpretation of the otoliths was passed on to subsequent readers. Furthermore, several age comparison studies have been conducted and a highly acceptable level of reproducibility was always obtained. An example of one of these age comparison studies conducted in 2003 is shown in Appendix V. These comparisons involved the main age reader over the period 1964-2003 (John Molloy) and his successor, the present author (2002-present). This study shows a high degree of precision and reproducibility between these readers, Eugene Mullins, who was the primary reader for the VIaS and VIIbc herring stock (1998-present) and Jan Beintema, who is the Netherlands Institute (RIVO) most experienced herring age reader.

The percentage age distribution for the Celtic Sea and VIIj combined stock area is presented in Table 3.3.1 and Figure 3.3.1 for the period 1960/1961 to 2006/2007. The percentage age distribution for each ICES Division (VIIaS, VIIg, VIIj respectively) is presented in Tables 3.3.2 to 3.3.4 and in Figures 3.3.2 to 3.3.4. It can be seen in Table 3.3.2 and Figure 3.3.2 that there are no data present from 1986/1987 to 1988/1989 for VIIaS and the reasons for these gaps are unknown. Data were collected from VIIg and VIIj for this period but there are other years where there are no samples from VIIg and VIIj also (Table 3.3.3 and Table 3.3.4). Despite the differences in sampling coverage between ICES Divisions, a similar age distribution is apparent and the same year classes were strong in each individual division and in the combined stock area.

These included the 1956/1957, 1985/1986, 1990/1991 and 2000/2001 year classes. It was not possible to discern if the 1985/1986 cohort was well represented in catches for Division VIIaS as samples were not available in the period which the cohort would have been present in the catches

In 2006/2007, there was a strong dominance of 2-ringers (2004/2005 year class) in the Celtic sea and VIIj combined. The 5-ringers in 2006/2007 (2001/2002 year class) were weak as they were in previous seasons. The 2-ringers have been the dominant age in catches in general throughout the series. The 1-ringers were strong in the mid 1970s and in the early 1980s but have become less evident since then. The strong dominance of 2-ringers for 2006/2007 can be seen in VIIaS and VIIg but not in VIIj as there were very little samples collected in VIIj at that time.

It can be seen that 2- and 3-winter ring fish were always dominant, in all areas. Also throughout most of the time series strong and weak cohorts could be tracked from year to year. This underlines the quality of the age reading, which consistently tracked these cohorts. The recent very poor year class (2001/2002) can clearly be seen in these data, showing that age reading continues to be consistent from year to year.

A selection pattern may vary over time, due to changes in targeting younger fish, movement to different grounds or different gears. It is beyond the scope of this study to investigate differing selection in the fishery over time. However it can be seen that 2- and 3-ringer always dominated.

Table 3.3.1 Comparison of age distribution (percentages) for the Celtic Sea and Division VIIj over the time series. Age in winter rings, 1 ringer = 2 year old.

Fishing Season	1	2	3	4	5	6	7	8	9+
1960/1961	1	36	39	5	2	6	5	3	2
1961/1962		12	14	49	2	4	6	4	9
1962/1963	14	28	19	25	5	1	3	2	2
1963/1964	2	64	9	5	13	2	1	2	2
1964/1965	15	25	29	8	4	12	2	1	4
1965/1966	1	56	12	12	3	4	8	1	2
1966/1967	19	23	34	6	7	2	2	4	2
1967/1968	12	40	13	19	5	4	2	2	2
1968/1969	7	36	26	7	14	3	3	1	4
1969/1970	8	47	18	12	5	6	2	1	1
1970/1971	2	39	32	10	7	5	3	1	1
1971/1972	9	23	23	27	8	5	3	2	1
1972/1973	5	69	9	7	5	2	1	1	0
1973/1974	10	34	36	8	5	4	2	1	1
1974/1975	7	49	18	17	5	3	2	1	0
1975/1976	27	29	19	8	10	4	2	1	1
1976/1977	22	36	20	8	3	4	4	1	1
1977/1978	30	24	22	12	5	3	2	1	1
1978/1979	6	38	28	21	3	2	1	1	1
1979/1980	24	30	26	8	8	2	1	2	0
1980/1981	8	40	21	13	7	5	2	2	0
1981/1982	44	20	23	5	5	1	1	0	0
1982/1983	22	54	12	6	2	3	1	1	
1983/1984	10	62	23	3	2	0	0	0	
1984/1985	14	54	22	7	1	1	0	0	
1985/1986	12	45	27	12	3	0	0	0	
1986/1987	3	53	23	14	6	1	0	0	
1987/1988	4	44	27	14	9	2	1	0	0
1988/1989	3	60	23	7	5	2	1	1	
1989/1990	7	29	42	11	6	2	2	1	0
1990/1991	3	36	19	29	7	3	2	1	0
1991/1992	1	38	25	10	19	3	2	1	0
1992/1993	11	18	24	21	8	14	2	2	
1993/1994	2	72	7	8	4	2	5	1	
1994/1995	9	27	53	3	2	3	1	1	0
1995/1996	8	49	12	24	2	2	1	2	0
1996/1997	3	44	28	5	14	2	2	3	0
1997/1998	3	28	37	19	6	5	1	1	0
1998/1999	4	33	23	23	11	3	3	1	0
1999/2000	15	26	27	12	12	6	1	2	0
2000/2001	12	48	16	11	5	5	2	1	0
2001/2002	12	50	27	5	3	2	1	0	0
2002/2003	6	50	31	8	1	2	0	0	0
2003/2004	3	56	26	11	3	0	0	0	
2004/2005	5	9	48	24	11	2	0	1	0
2005/2006	22	40	5	21	9	3	0	0	0
2006/2007	4	64	17	3	8	3	1	0	0

Table 3.3.2 Comparison of age distribution (percentages) for ICES Division VIIaS over the time series. Age in winter rings, 1 ringer = 2 year old.

Fishing Season	1	2	3	4	5	6	7	8	9+
1960/1961	1	36	39	5	2	6	5	3	2
1961/1962	0	12	14	49	2	4	6	4	9
1962/1963	14	28	19	25	5	1	3	2	2
1963/1964	2	64	9	5	13	2	1	2	2
1964/1965	15	25	29	8	4	12	2	1	4
1965/1966	1	55	12	13	3	4	8	1	2
1966/1967	16	28	30	5	9	3	3	4	2
1967/1968	6	44	15	17	6	6	2	2	3
1968/1969	8	38	26	6	10	3	4	1	4
1969/1970	7	56	16	10	4	4	2	1	1
1970/1971	1	40	36	9	7	3	2	1	1
1971/1972	9	27	25	25	5	5	2	1	1
1972/1973	5	70	10	6	5	1	1	0	0
1973/1974	9	33	36	8	5	4	2	1	1
1974/1975	6	48	19	17	4	2	2	1	0
1975/1976	28	33	20	6	7	3	1	1	1
1976/1977	33	34	19	7	3	2	2	0	0
1977/1978	60	9	14	7	4	2	2	1	1
1978/1979	9	54	29	5	1	1	0	0	0
1979/1980	37	27	28	4	3	0	0	0	0
1980/1981	14	54	9	7	5	2	1	0	
1981/1982	25	34	30	3	4	1	0	0	
1982/1983	24	62	8	4	1	2	0	0	
1983/1984	7	71	18	2	1	0	0	0	
1984/1985	3	72	19	5	0	0	0	0	
1985/1986	9	40	35	15	1	0			
1986/1987									
1987/1988									
1988/1989									
1989/1990	2	31	32	22	3	4	3	1	
1990/1991	2	59	16	15	5	1	1	0	
1991/1992	1	42	31	9	12	3	1	1	0
1992/1993	7	16	26	30	7	11	3	1	
1993/1994	2	82	5	4	4	1	1	0	
1994/1995	11	33	47	2	1	5	0	1	0
1995/1996	9	51	16	19	1	2	1	1	0
1996/1997	1	59	22	7	9	1	0	1	
1997/1998	2	25	41	20	6	5	1	1	0
1998/1999	4	42	18	20	10	3	2	1	0
1999/2000	9	30	29	11	12	8	1	1	0
2000/2001	21	52	11	7	3	4	1	1	0
2001/2002	15	63	17	2	2	1	1	0	0
2002/2003	3	54	35	7	1	1			
2003/2004	1	63	24	10	3	0	0		
2004/2005	6	5	51	24	11	2	0	1	0
2005/2006	29	41	2	18	7	3	0		
2006/2007	3	69	16	2	7	3	1	0	0

Table 3.3.3 Comparison of age distribution (percentages) for the ICES Division VIIg over the time series. Age in winter rings, 1 ringer = 2 year old.

Fishing Season	1	2	3	4	5	6	7	8	9+
1960/1961									
1961/1962									
1962/1963									
1963/1964									
1964/1965									
1965/1966	2	64	9	10	2	4	6	1	3
1966/1967	14	19	42	5	6	2	3	5	3
1967/1968	18	36	10	22	4	3	2	3	2
1968/1969	5	36	26	13	8	9	2	1	1
1969/1970	5	36	26	13	8	9	2	1	1
1970/1971	0	17	23	23	11	18	5	1	2
1971/1972	8	6	17	31	18	8	4	5	2
1972/1973	4	63	6	11	9	5	2	1	0
1973/1974	17	44	28	1	1	1	6	1	
1974/1975	8	49	14	18	5	4	2	0	1
1975/1976	30	21	20	10	13	2	2	1	1
1976/1977	9	51	20	6	5	3	2	1	2
1977/1978	4	68	23	0	2	1	1	1	1
1978/1979	7	40	24	22	2	2	1	0	0
1979/1980	9	27	50	5	6	0	0	1	
1980/1981	4	36	25	17	6	6	2	2	0
1981/1982	31	14	27	11	11	3	2	1	0
1982/1983	26	44	9	8	5	6	1	1	
1983/1984	5	55	32	3	3	0	0	1	
1984/1985	17	39	28	13	2	1	0	0	
1985/1986	15	49	22	9	5	1	0	0	
1986/1987	3	48	25	17	7	1	0	0	
1987/1988	3	44	27	14	9	2	0	0	0
1988/1989	2	59	24	6	4	2	1	0	
1989/1990	9	34	38	10	6	1	1	0	0
1990/1991	4	28	24	35	5	2	1	0	
1991/1992	1	31	28	13	21	3	2	1	0
1992/1993	18	28	23	10	7	12	1	1	
1993/1994	0	74	10	7	3	3	2	1	
1994/1995	6	29	54	3	3	2	1	1	
1995/1996	8	38	11	33	2	2	5	2	
1996/1997	3	51	25	6	14	1	1	1	0
1997/1998	2	23	43	23	6	2	1	1	
1998/1999	4	27	24	27	12	3	2	1	0
1999/2000	4	28	29	13	16	6	2	2	
2000/2001	9	52	17	9	4	6	2	1	1
2001/2002	7	51	31	5	3	1	1	0	0
2002/2003	4	41	37	12	1	1	0	0	0
2003/2004	3	49	29	14	4	0	0	0	
2004/2005	5	19	44	25	7	1			
2005/2006	19	42	6	21	9	2	0	0	
2006/2007	4	63	19	3	9	3	0	0	0

Table 3.3.4 Comparison of age distribution (percentages) for the ICES Division VIIj over the time series. Age in winter rings, 1 ringer = 2 year old.

Fishing Season	1	2	3	4	5	6	7	8	9+
1960/1961									
1961/1962									
1962/1963									
1963/1964									
1964/1965									
1965/1966									
1966/1967	46	8	34	8	3	1	0	1	0
1967/1968	14	36	22	15	8	1	1	0	2
1968/1969									
1969/1970	16	29	13	20	6	12	3	1	1
1970/1971	7	56	12	7	5	7	4	1	2
1971/1972									
1972/1973									
1973/1974									
1974/1975									
1975/1976	7	21	13	13	12	21	2	6	4
1976/1977	4	13	30	14	3	7	18	4	6
1977/1978	7	29	22	23	5	5	4	5	1
1978/1979	1	13	28	38	6	5	3	4	2
1979/1980	13	37	17	12	14	3	2	3	0
1980/1981	2	23	30	14	12	10	4	4	
1981/1982	66	12	17	2	1	2	0	0	
1982/1983	16	50	18	9	2	2	2	1	
1983/1984	15	38	32	8	5	1	1	1	
1984/1985	36	26	23	9	3	1	0	0	
1985/1986	23	51	14	9	3	0	0		
1986/1987	3	61	19	10	4	2	0	0	
1987/1988	5	40	29	12	9	2	2	1	
1988/1989	3	59	11	11	6	4	2	4	
1989/1990	5	19	52	9	7	3	2	2	0
1990/1991	1	23	18	36	10	7	3	2	1
1991/1992	1	29	14	8	36	5	5	3	
1992/1993	18	13	20	9	10	24	3	4	
1993/1994	1	42	9	20	6	3	18	2	
1994/1995	6	6	72	4	2	3	3	3	
1995/1996	7	49	6	29	3	2	1	3	0
1996/1997	5	25	38	3	18	3	3	5	0
1997/1998	9	37	25	15	3	7	1	2	0
1998/1999	7	31	29	15	10	2	4	2	0
1999/2000	38	18	21	11	7	3	1	1	0
2000/2001	7	30	22	19	11	5	5	1	1
2001/2002	16	34	29	8	6	4	1	1	0
2002/2003	15	57	14	6	2	3	1	0	0
2003/2004	4	48	39	6	3	1			
2004/2005	0	38	36	18	5	1	1	1	0
2005/2006	14	32	12	29	11	2	0	0	0
2006/2007	12	6	18	29	27	7	0	1	

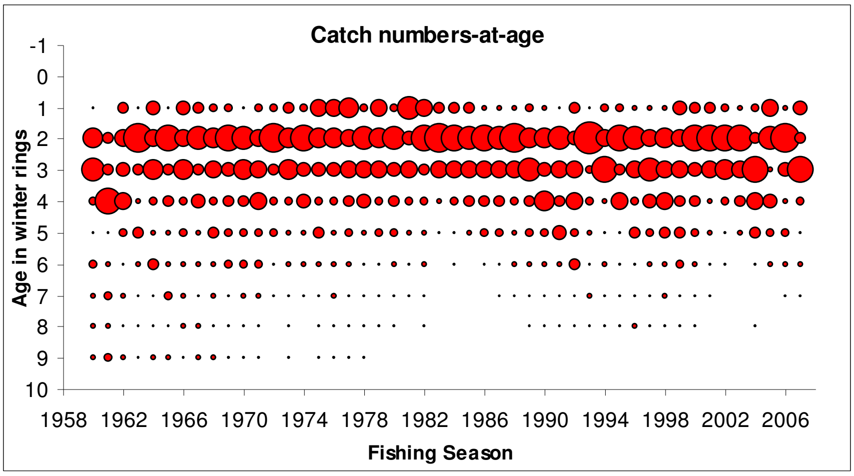


Figure 3.3.1. Catch numbers-at-age (%) for the Celtic sea and Division VIIj

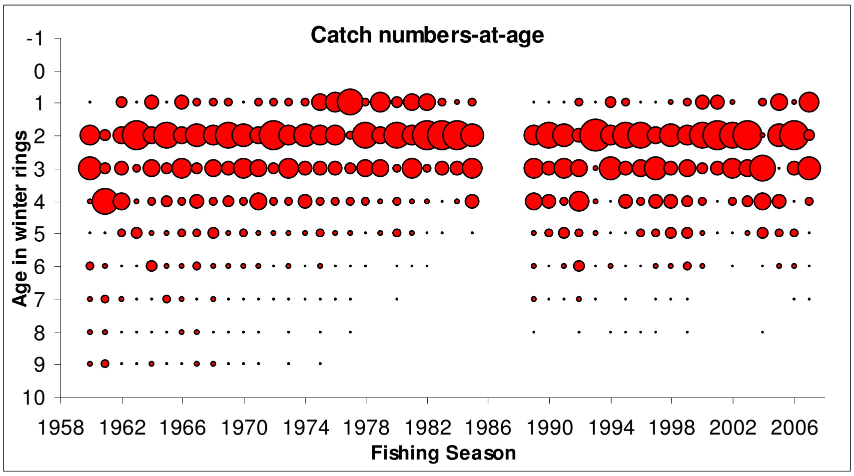


Figure 3.3.2. Catch numbers-at-age (%) for ICES Division VIIaS over the time series. Age in winter rings and season indicated by first year.

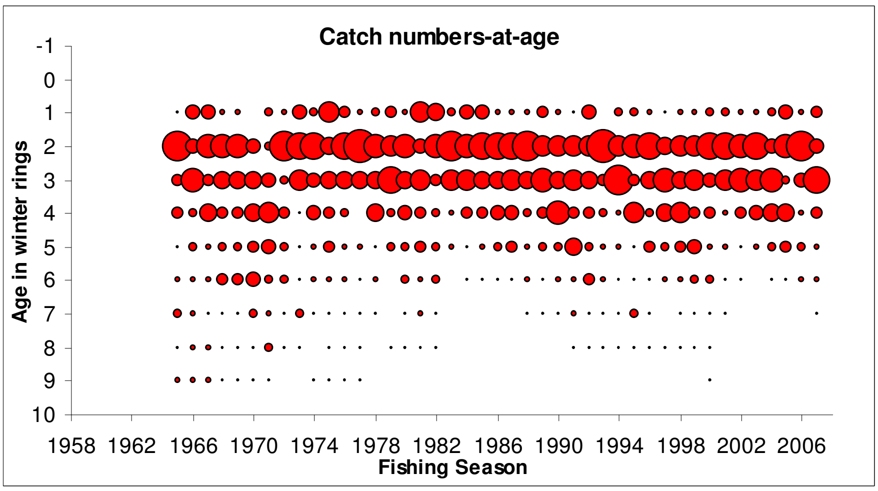


Figure 3.3.3. Catch numbers-at-age (%) for ICES Division VIIg over the time series. Age in winter rings and season indicated by first year.

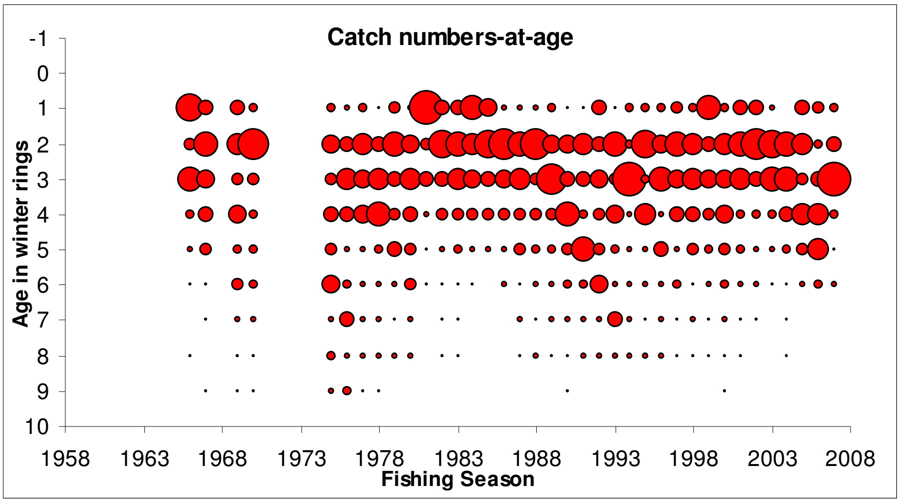


Figure 3.3.4. Catch numbers-at-age (%) for ICES Division VIIj over the time series. Age in winter rings and season indicated by first year.

3.4 Mean length and mean weight at age

Mean length at age and mean weight at age data were available from two sources:

- Present study, based on reconstructed, archived and inputted raw data from 1960 to 2007. These data will here after be referred to as the "reconstructed data".
- Data presented at the ICES Herring Assessment Working Group report (Anon, 2007).

These data differ because the latter were based on quarterly or in some cases monthly "summaries" which have been raised to the estimated official landings while the reconstructed data are based on seasonal "summaries" using a standard landings tonnage. The ICES data also contain foreign sampling data from foreign catches raised to the international landings estimates.

Mean length at age is presented in Table 3.4.1 for the reconstructed data. In addition, Table 3.4.2 contains mean length at age data from historic data from the Dunmore

East fishery between 1921 and 1963, as presented by Burd and Bracken (1965) and references therein. Figure 3.4.1 shows the mean length at age from the present study and Figure 3.4.2 shows the mean length at age from the historic source (Burd and Bracken, 1965) combined with the reconstructed data from the present study. Data from 1921 to 1963 are taken from Burd and Bracken (1965) and from 1964 onwards are taken from the reconstructed data.

The data presented by Burd and Bracken (1965) and the present data overlap for the years 1961-1963. The difference in mean length between the two sets of data is from 0.1% to 5% with just one length (2wr) in 1961 with a difference of 5%. This is probably due to slight differences in the calculating procedures used.

Mean length for the most abundant age groups increased to above the long term mean from the early 1960's, and reached a peak in 1975. The long term mean is the mean of mean length at age by year. After 1975 mean length declined, falling below the long term mean again, by the early 1990s (Figure 3.4.1 and Figure 3.4.2.) Mean lengths for the most abundant age groups in the catches (2 and 3 ringers) are 23.37cm and 24.73cm in 2007, having declined from 27.86cm and 29.12cm respectively in 1975. This represents a decline of 15% and 16% respectively. Length at age appears to have been increasing in the 1920s, but had declined to below long term mean again by the 1950s.

For the reconstructed data, mean weight at age is presented in Table 3.4.3 and Figure 3.4.3. The mean weight at age, taken from the ICES HAWG 2007 (Anon, 2007) is presented in Table 3.4.4. and Figure 3.4.4. It can be seen from the reconstructed data that the mean weights increased from 1958 to mid 1970s and then decreased thereafter. As there were no weight measurements taken prior to 1975, a length weight relationship was applied to the mean length at age data prior to 1975 to derive the mean weights at age data used by ICES Herring WG. In order to generate mean weights for this period a length weight regression was calculated for the entire period of extant data in 2000. Length weight relationships for herring have been shown to be robust spatially and temporally for herring in the North Sea (Hammer *et al* 1996) and the spread of data in the case of Celtic Sea herring showed no trends or biases across time or age. (Anon, 2000).

In addition, Figure 3.4.3 shows the decline in mean weight at age from 1975 to 2006. It can be seen from Table 3.4.3 that the 2006 mean weights for the main age groups in the catches (2 and 3 ringers) are 50% smaller than in 1975. This strong decline is also seen in Table 3.4.4. and Figure 3.4.4 and the current mean weights are similar to those from the late 1950s and early 1960s.

Mean length at age is shown by cohort in Figure 3.4.5 a. A median mean length value was calculated for 3 ringers and the graphs show the year classes above and below this median. Mean weight at age is shown by cohort in Figure 3.4.5 b. A median mean weight value was calculated for 3 ringers and the graphs show the year classes above and below this median. It can be seen that among the cohorts that grew the slowest (attained low levels of length or weight) were 1998/1999, 1999/2000 and 2001/2002. Among the fast growing were those from 1971/1972 to 1978/1979.

Table 3.4.1 Mean length at age by fishing season (e.g. Q4 1960 and Q1 1961 = 1960) from the reconstructed data. Age in winter rings.

Year	0	1	2	3	4	5	6	7	8	9+
1960		21.25	24.73	26.98	28.71	28.90	28.96	29.37	29.44	30.72
1961			26.17	27.04	28.05	28.25	27.50	28.58	29.50	29.36
1962		22.90	25.81	27.02	27.90	28.87	29.60	29.70	29.84	29.74
1963		23.43	25.59	28.16	28.75	29.24	29.69	29.87	30.36	30.59
1964		23.46	25.59	27.65	28.93	29.45	29.73	29.92	30.23	30.65
1965		23.94	25.76	27.66	29.04	29.92	30.17	30.22	30.72	30.94
1966		23.76	26.49	28.22	29.37	29.94	30.40	30.61	30.45	30.89
1967		24.09	26.36	27.98	29.22	30.13	30.46	30.67	30.75	30.98
1968		24.3	26.89	28.19	29.02	29.92	30.53	30.74	30.91	31.1
1969		24.57	26.57	28.47	29.17	29.91	30.26	30.82	30.85	31.09
1970		24.03	26.66	28.45	29.48	30.01	30.24	30.80	31.46	31.31
1971		24.15	26.72	28.37	29.45	30.28	30.65	30.89	31.05	31.50
1972		24.98	27.06	28.14	29.26	30.20	30.71	30.85	31.24	31.66
1973		24.37	27.39	28.67	29.49	30.32	30.73	30.86	31.73	31.13
1974	19.75	25.79	27.62	28.90	29.53	30.08	30.72	30.99	31.65	31.62
1975	19.00	25.12	27.86	29.12	29.96	30.39	30.76	31.15	31.36	31.71
1976	18.70	24.89	27.00	27.68	29.72	30.83	30.77	30.62	31.12	31.18
1977	19.25	25.13	27.39	28.49	28.91	29.86	30.62	30.69	31.48	31.25
1978	19.47	24.71	27.74	29.04	29.59	29.72	30.64	30.99	31.11	31.74
1979	21.25	24.75	26.62	28.57	29.62	30.28	30.47	30.92	31.11	31.69
1980	16.84	24.36	27.12	28.18	29.68	30.57	30.91	30.90	31.56	32.25
1981	16.67	23.59	27.00	28.99	30.26	31.04	31.24	31.88	31.78	33.75
1982	18.55	24.10	26.31	27.73	29.80	30.76	31.21	30.97	31.87	
1983	19.25	24.36	26.11	28.57	29.21	30.63	31.12	30.17	32.46	34.25
1984	17.25	23.07	25.48	27.55	29.17	29.74	30.97	31.37	31.79	
1985	17.00	24.14	25.83	26.98	28.39	29.85	30.22	29.94	32.12	
1986		23.71	26.33	27.47	28.22	29.37	30.23	31.00	31.98	
1987		22.68	25.23	27.68	28.33	28.78	29.60	30.21	31.04	31.46
1988	16.75	22.22	25.23	27.03	28.50	28.89	29.26	29.93	31.05	
1989		23.36	25.22	26.51	27.73	28.81	29.46	29.73	30.65	30.91
1990		23.29	25.43	26.65	27.35	28.36	29.52	29.41	30.47	30.02
1991	16.35	22.47	25.31	26.99	27.71	28.01	28.77	29.72	30.22	30.19
1992	19.25	22.92	25.02	26.40	27.66	28.34	28.49	29.11	30.24	
1993		22.84	24.98	26.62	27.69	28.58	28.51	28.86	29.73	
1994	18.25	22.54	25.26	26.92	27.71	28.43	28.86	29.36	29.50	29.92
1995		22.74	25.18	26.64	27.83	28.32	28.67	29.22	29.70	30.25
1996		22.45	24.86	26.71	27.42	28.49	28.98	29.48	30.01	29.77
1997		22.41	24.67	26.00	26.92	27.96	28.64	29.05	29.70	30.38
1998		23.13	24.69	26.45	27.03	27.71	28.20	29.03	29.42	30.70
1999		22.90	25.00	26.46	27.40	27.85	28.13	28.63	29.22	29.25
2000		22.58	24.44	26.48	27.50	28.10	28.21	28.82	29.50	29.65
2001		22.07	23.86	25.65	27.00	27.68	28.30	28.27	29.25	29.94
2002	19.76	22.74	23.77	25.21	26.17	27.45	27.79	27.84	28.79	28.81
2003		22.52	23.45	25.02	25.91	26.78	27.21	27.90	28.71	
2004		21.64	24.81	25.16	26.04	26.50	27.19	29.18	30.98	30.25
2005		21.48	23.50	26.07	26.19	26.83	27.17	28.30	28.57	32.00
2006	16.58	22.39	23.44	24.93	26.69	26.65	27.13	27.54	26.67	28.73
2007	17.89	21.14	23.37	24.73	25.81	26.93	27.12	27.55	27.7	31.25

Table 3.4.2 Mean length at age for the Dunmore East fishery, from historic sources (Burd and Bracken, 1965 and references therein). Age in winter rings and, for comparison with the published material, in years.

Winter Rings	1	2	3	4	5	6	7	8	9	
1921/1923		24.5	26.4	28.2	29.1	29.7	29.9			Le Danois and Heldt (1924)
1923/1930		25.5	26.8	27.6	28.7	29.3	29.7	30.1		Watkin (1933b)
1926/1930		26.3	27.7	28.5	28.9	29.2	29.8	29.9		Watkin (1933a)
1921/1941	22.4	24.7	26.7	28	28.7	29.5	-	-		Farran (1944)
1952		24.3	25.2	27	27.4	28.4		28.4		Gilis (1953)
1955		24.1	26.1	27.3	28.5	29	29.4	30.2	30.3	Gilis (1956)
1957		25	26.4	27.7	28.2	28.8	29.2	29.5	29.6	Gilis (1958)
1957		25	26.9	27.9	28.3	28.6	29.4	29.3		Burd (unpublished)
1958		26.1	27.1	27.9	28.6	28.8	29.4	29.5	30.1	Burd (unpublished)
1958		24.1	26.7	27.8	28.7	29.2	29.6	29.8	29.4	Bracken (unpublished)
1959		25.9	27.7	28	28.7	29.4	29.4			Burd (unpublished)
1959		24.3	26.9	27.8	28.5	28.9	29.2	29.7	29.5	Bracken (unpublished)
1960		24.3	26.6	28.2	28.7	28.8	29.4	29.2	29.7	Bracken (unpublished)
1961		24.8	26.4	27.8	28.8	28.9	29.4	29.8	30.1	Bracken (unpublished)
1962		25.5	26.7	27.4	28.5	29.2	29.3	29.5	29.6	Bracken (unpublished)
1963		25.4	28.2	28.7	29.2	29.7	30	30.3	30.3	Bracken (unpublished)

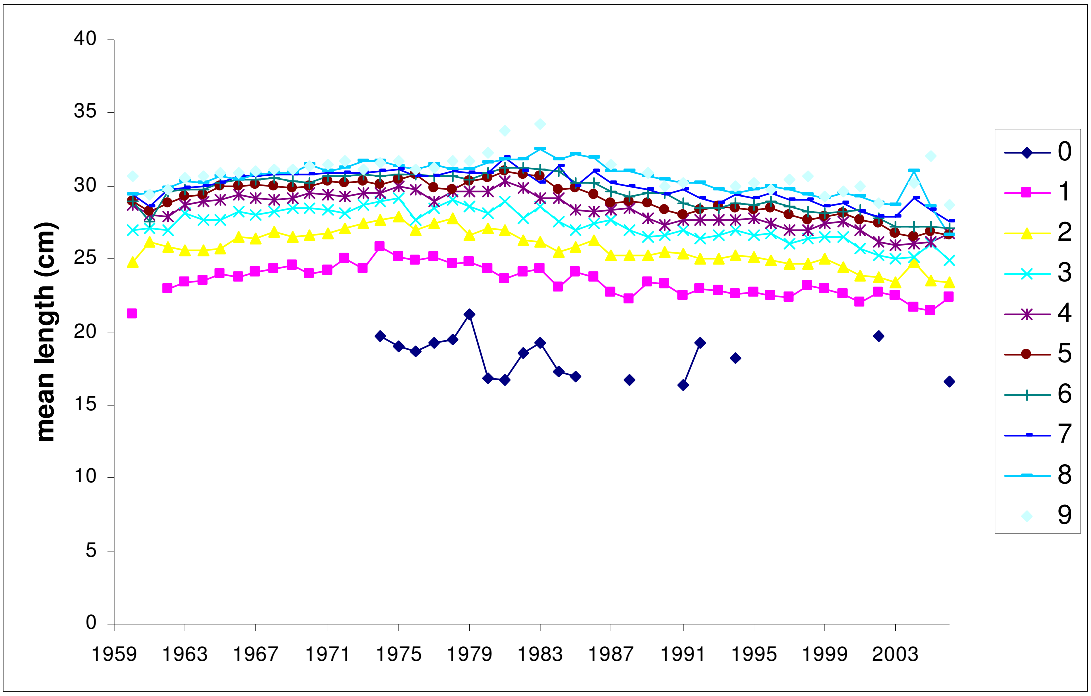


Figure 3.4.1 Mean length at age by season (e.g. Q4 1960 and Q1 1961 = 1960) from the reconstructed data. Age in winter rings.

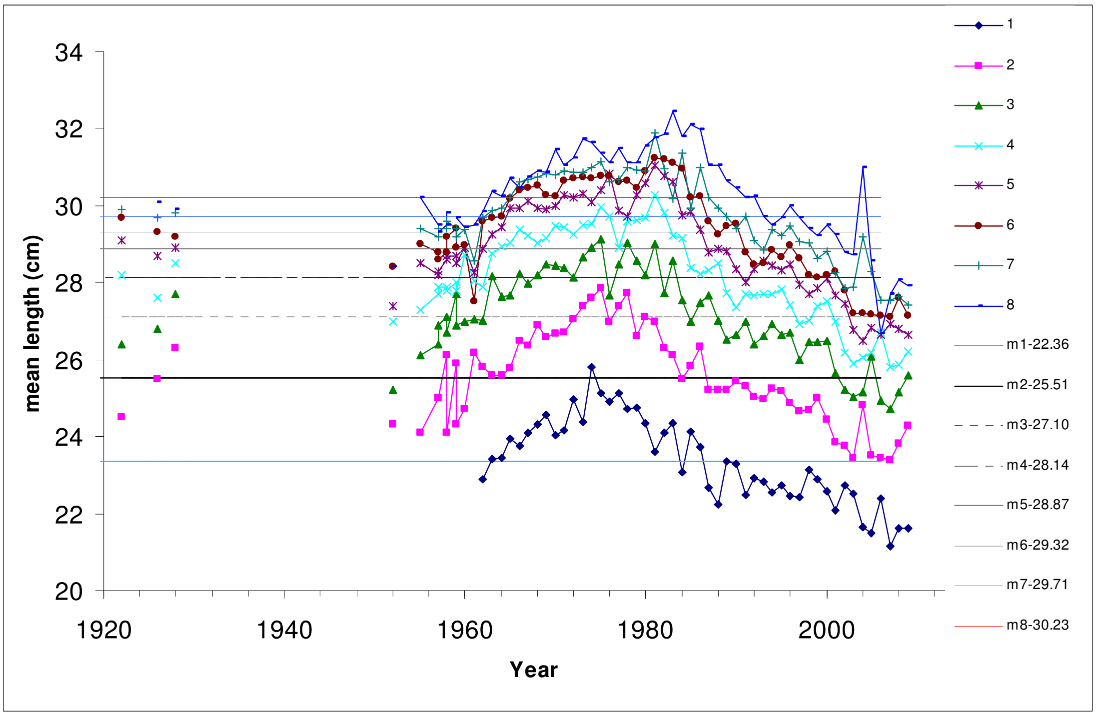


Figure 3.4.2 Mean length at age from historic sources (Burd *et al*, 1965) and references therein. Data from 1964 onwards are from reconstructed data. Long term means are shown for each age and are labelled m1-m8. The data from the 1920s are depicted as single years though they represent a group of years (Table 3.4.2).

Table 3.4.3 Mean weight-at-age (kg) for fishing season (e.g. Q4 1960 and Q1 1961 = 1960) from reconstructed data. Age in winter rings.

Year	0	1	2	3	4	5	6	7	8	9+
1975	0.05	0.14	0.19	0.22	0.25	0.26	0.27	0.28	0.29	0.30
1976	0.05	0.13	0.17	0.19	0.24	0.27	0.26	0.26	0.28	0.28
1977	0.05	0.12	0.16	0.19	0.20	0.22	0.24	0.24	0.27	0.26
1978	0.05	0.12	0.18	0.21	0.22	0.23	0.25	0.26	0.27	0.28
1979	0.07	0.12	0.16	0.20	0.22	0.24	0.24	0.26	0.26	0.28
1980	0.04	0.12	0.17	0.20	0.23	0.26	0.26	0.26	0.28	0.30
1981	0.03	0.11	0.17	0.22	0.26	0.28	0.29	0.31	0.31	0.38
1982	0.05	0.11	0.15	0.17	0.22	0.24	0.25	0.25	0.26	
1983	0.05	0.12	0.15	0.20	0.21	0.25	0.26	0.24	0.31	0.37
1984	0.04	0.10	0.14	0.18	0.21	0.22	0.25	0.26	0.27	
1985	0.03	0.11	0.14	0.17	0.20	0.24	0.25	0.24	0.30	
1986		0.11	0.16	0.18	0.20	0.23	0.25	0.28	0.31	
1987		0.09	0.13	0.18	0.20	0.21	0.23	0.25	0.27	0.28
1988	0.03	0.09	0.13	0.17	0.20	0.21	0.22	0.24	0.27	
1989		0.11	0.13	0.15	0.17	0.19	0.21	0.21	0.23	0.24
1990		0.11	0.14	0.16	0.17	0.19	0.21	0.21	0.23	0.22
1991	0.03	0.09	0.14	0.17	0.18	0.19	0.21	0.23	0.24	0.24
1992	0.05	0.09	0.13	0.15	0.18	0.19	0.20	0.21	0.24	
1993		0.10	0.13	0.16	0.18	0.20	0.20	0.21	0.23	
1994	0.05	0.09	0.14	0.17	0.18	0.20	0.21	0.22	0.23	0.24
1995		0.09	0.13	0.15	0.18	0.19	0.20	0.21	0.22	0.23
1996		0.09	0.12	0.15	0.17	0.19	0.20	0.21	0.22	0.22
1997		0.09	0.12	0.14	0.16	0.18	0.19	0.20	0.22	0.23
1998		0.10	0.12	0.15	0.16	0.18	0.19	0.20	0.21	0.24
1999		0.09	0.13	0.15	0.17	0.18	0.19	0.20	0.22	0.22
2000		0.09	0.12	0.15	0.18	0.19	0.19	0.21	0.22	0.23
2001		0.08	0.11	0.14	0.17	0.18	0.20	0.20	0.22	0.24
2002	0.07	0.09	0.11	0.13	0.15	0.18	0.19	0.19	0.21	0.21
2003		0.09	0.10	0.12	0.14	0.15	0.16	0.17	0.19	
2004		0.08	0.12	0.13	0.15	0.16	0.17	0.22	0.27	0.25
2005		0.07	0.10	0.14	0.14	0.16	0.16	0.19	0.20	0.29
2006	0.04	0.09	0.10	0.12	0.15	0.15	0.16	0.16	0.15	0.18

Table 3.4.4 Mean weight-at-age (kg) taken from ICES HAWG report 2007 (Anon, 2007). Age in winter rings.

Year	1	2	3	4	5	6	7	8	9+
1958	0.10	0.12	0.16	0.19	0.21	0.22	0.23	0.23	0.23
1959	0.09	0.12	0.17	0.19	0.20	0.21	0.22	0.23	0.23
1960	0.09	0.12	0.16	0.19	0.21	0.21	0.22	0.23	0.24
1961	0.10	0.13	0.16	0.19	0.21	0.21	0.22	0.24	0.24
1962	0.11	0.15	0.17	0.19	0.21	0.23	0.23	0.24	0.24
1963	0.10	0.14	0.19	0.21	0.22	0.23	0.24	0.25	0.25
1964	0.11	0.14	0.18	0.22	0.23	0.23	0.24	0.25	0.25
1965	0.10	0.14	0.18	0.21	0.23	0.24	0.24	0.26	0.26
1966	0.12	0.15	0.19	0.21	0.24	0.25	0.24	0.25	0.26
1967	0.12	0.16	0.19	0.22	0.24	0.25	0.26	0.26	0.26
1968	0.12	0.17	0.20	0.22	0.24	0.25	0.26	0.26	0.27
1969	0.12	0.16	0.20	0.22	0.24	0.25	0.26	0.26	0.26
1970	0.13	0.16	0.20	0.23	0.24	0.25	0.26	0.28	0.27
1971	0.12	0.17	0.20	0.23	0.25	0.25	0.26	0.27	0.28
1972	0.13	0.17	0.19	0.22	0.25	0.26	0.26	0.27	0.29
1973	0.13	0.17	0.21	0.22	0.25	0.26	0.26	0.29	0.29
1974	0.14	0.18	0.21	0.23	0.24	0.26	0.26	0.29	0.27
1975	0.14	0.19	0.22	0.24	0.25	0.26	0.27	0.28	0.28
1976	0.14	0.17	0.21	0.24	0.26	0.27	0.28	0.29	0.29
1977	0.13	0.19	0.21	0.22	0.24	0.27	0.26	0.29	0.30
1978	0.13	0.19	0.22	0.24	0.28	0.28	0.29	0.30	0.30
1979	0.13	0.17	0.21	0.23	0.25	0.27	0.29	0.28	0.28
1980	0.12	0.17	0.21	0.24	0.26	0.28	0.27	0.27	0.28
1981	0.12	0.17	0.21	0.25	0.27	0.28	0.30	0.31	0.32
1982	0.12	0.15	0.19	0.24	0.26	0.27	0.28	0.29	0.29
1983	0.11	0.15	0.20	0.22	0.28	0.28	0.28	0.32	0.33
1984	0.09	0.14	0.19	0.21	0.21	0.25	0.25	0.26	0.26
1985	0.10	0.14	0.17	0.20	0.23	0.25	0.26	0.26	0.26
1986	0.11	0.16	0.17	0.19	0.22	0.25	0.28	0.28	0.33
1987	0.10	0.14	0.19	0.19	0.20	0.23	0.26	0.27	0.28
1988	0.10	0.13	0.17	0.20	0.21	0.22	0.24	0.26	0.28
1989	0.11	0.13	0.15	0.17	0.19	0.20	0.21	0.22	0.24
1990	0.10	0.14	0.15	0.17	0.19	0.21	0.21	0.23	0.25
1991	0.09	0.13	0.17	0.18	0.19	0.21	0.23	0.24	0.25
1992	0.10	0.12	0.15	0.18	0.19	0.19	0.21	0.23	0.25
1993	0.09	0.13	0.16	0.18	0.20	0.20	0.21	0.23	0.24
1994	0.10	0.14	0.17	0.18	0.19	0.21	0.22	0.22	0.23
1995	0.09	0.13	0.15	0.18	0.19	0.20	0.21	0.23	0.23
1996	0.09	0.12	0.15	0.16	0.19	0.20	0.21	0.22	0.23
1997	0.09	0.12	0.14	0.16	0.17	0.19	0.21	0.22	0.22
1998	0.10	0.12	0.15	0.16	0.17	0.19	0.20	0.20	0.23
1999	0.09	0.12	0.15	0.17	0.18	0.18	0.20	0.21	0.21
2000	0.09	0.11	0.15	0.17	0.19	0.19	0.20	0.21	0.22
2001	0.08	0.11	0.14	0.16	0.18	0.19	0.19	0.20	0.23
2002	0.10	0.12	0.14	0.16	0.19	0.20	0.20	0.21	0.23
2003	0.09	0.10	0.13	0.15	0.17	0.18	0.20	0.20	0.21
2004	0.08	0.13	0.13	0.15	0.16	0.17	0.20	0.22	0.23
2005	0.08	0.10	0.14	0.15	0.16	0.17	0.18	0.21	0.25
2006	0.09	0.11	0.13	0.15	0.15	0.17	0.17	0.19	0.20

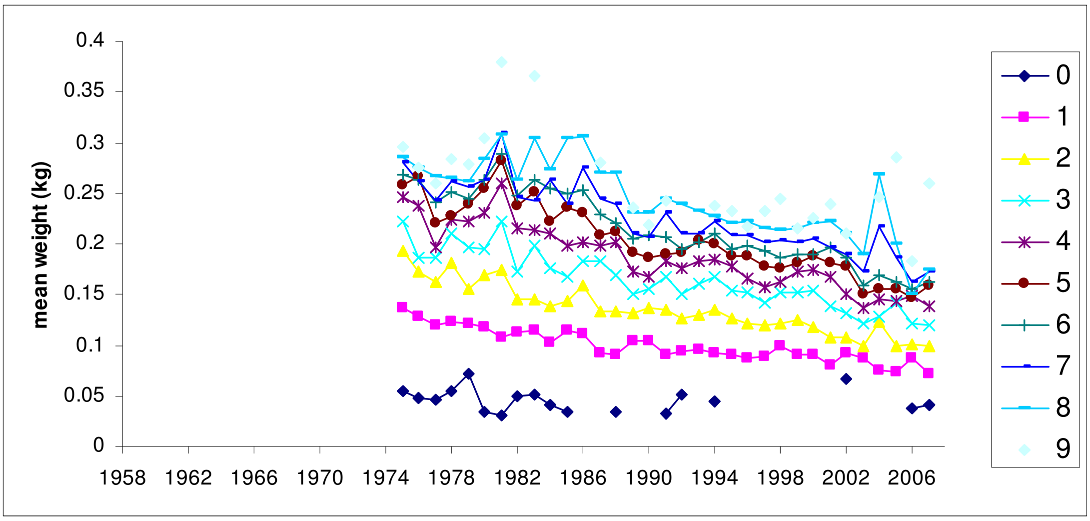


Figure 3.4.3 Mean weight-at-age (kg) for fishing season (e.g. Q4 1960 and Q1 1961 = 1960) from reconstructed data.

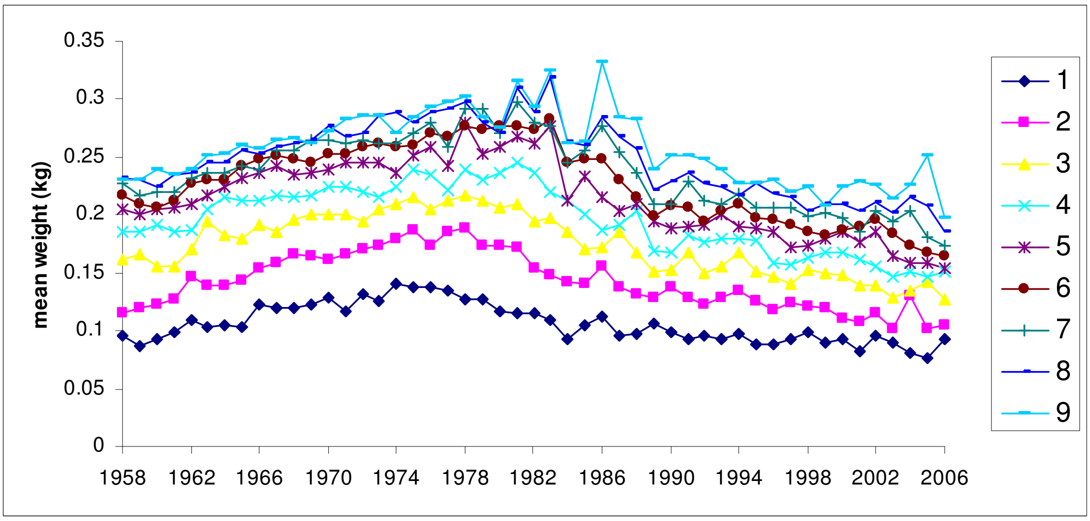
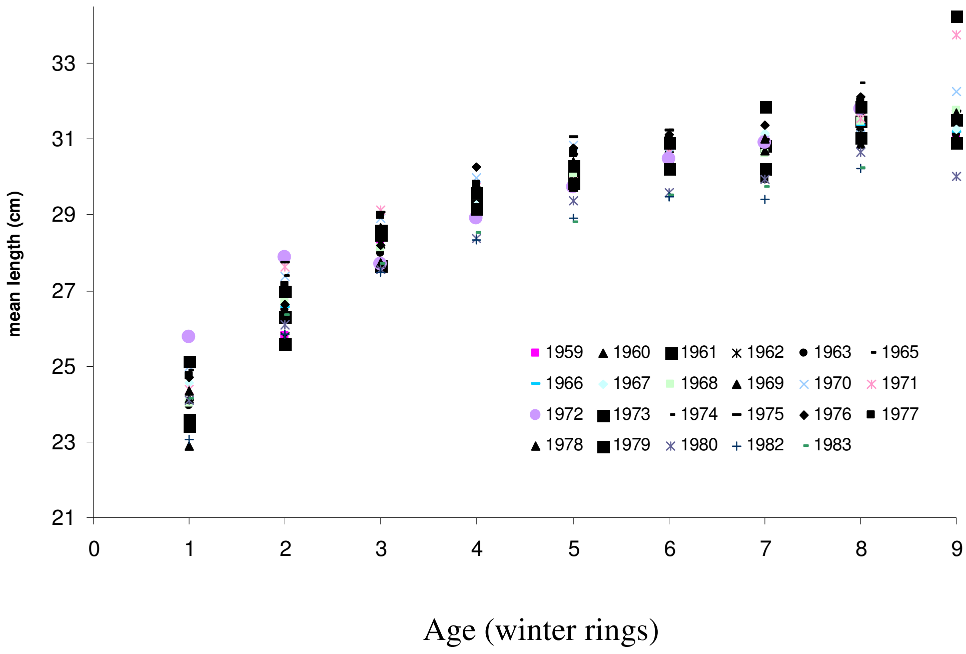


Figure 3.4.4 Mean weight-at-age (kg) taken from ICES HAWG report 2007 (Anon, 2007)



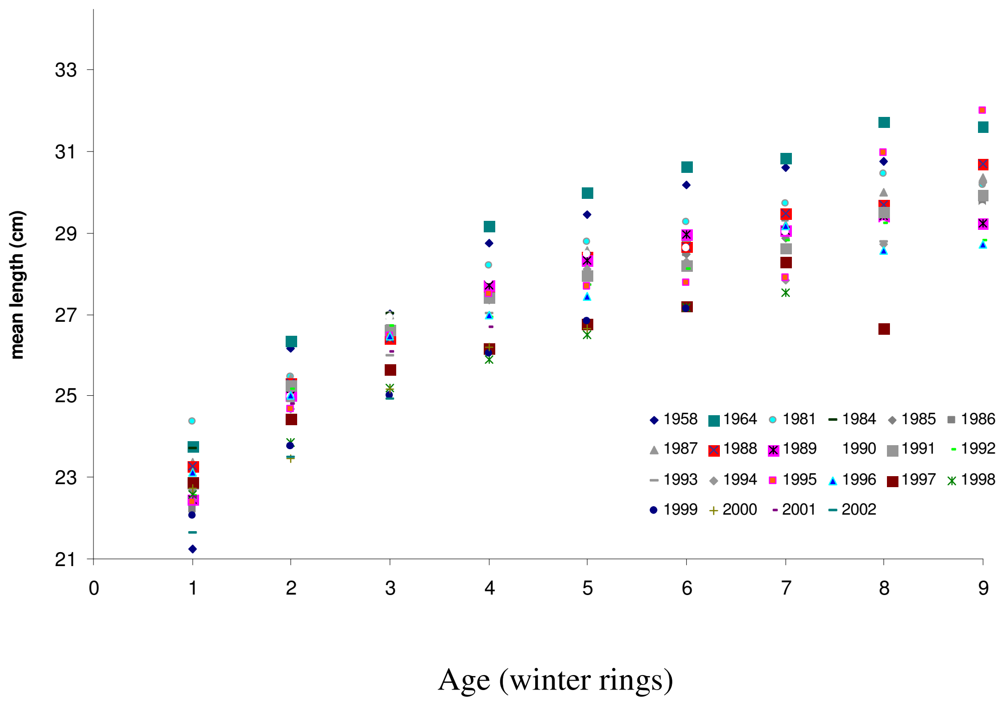


Figure 3.4.5a Mean length at age by cohort above and below the median value of 3ringers which is 27.255cm (1st graph = high mean lengths and 2nd graph = low mean lengths).

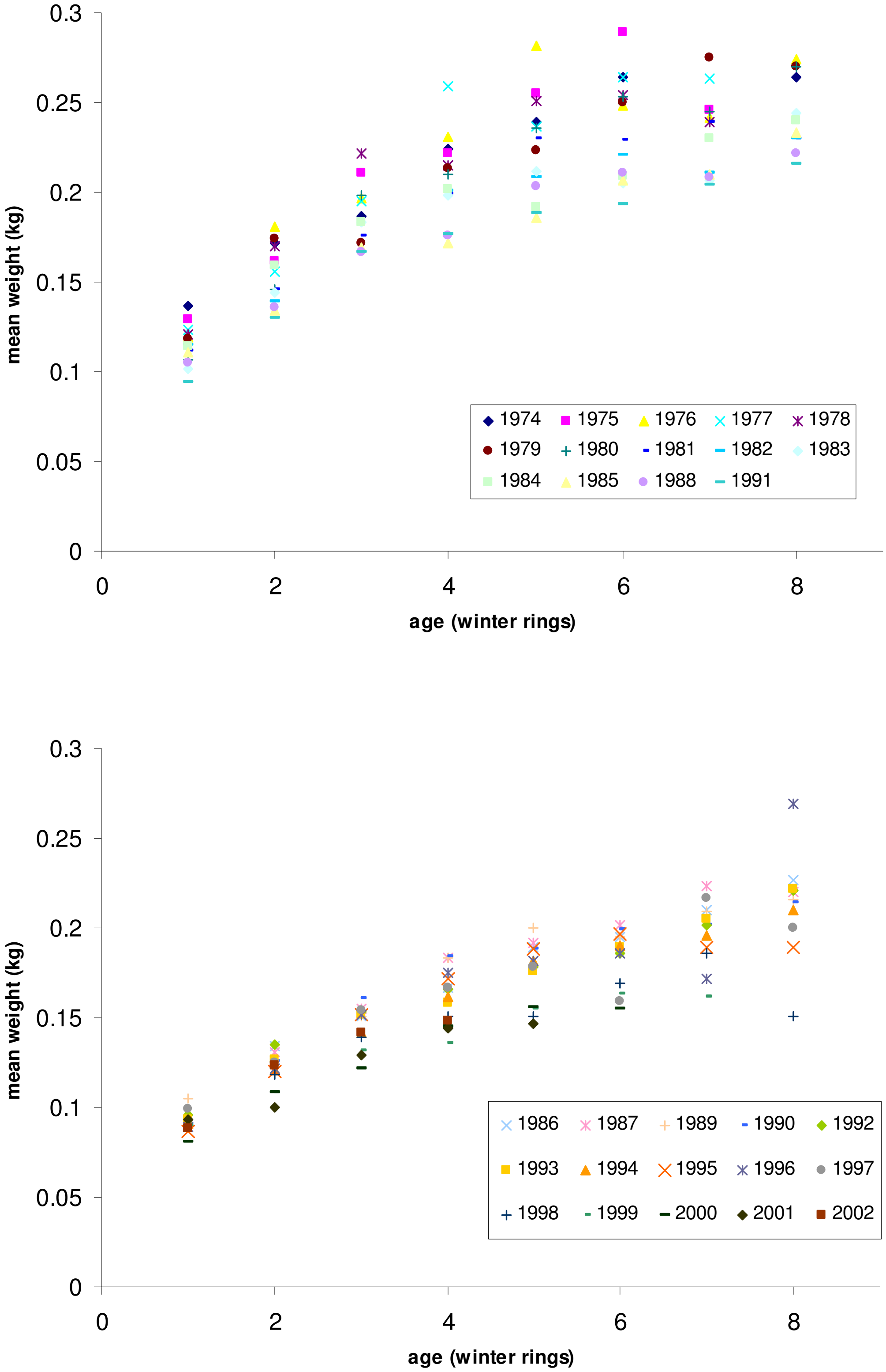


Figure 3.4.5b Mean weight-at-age by cohort above and below the median value of 3ringers which is 0.164kg (1st graph = high mean weights and 2nd graph = low mean weights).

3.5 Length Weight Relationship and Condition Factor

Length weight relationship data was used to determine the length weight regressions. The slopes (b) and intercepts (a) and the co-efficient of determination (r^2) of this regression are presented in Table 3.5.1. These data are from 1975 – 2006 because there was no weight data collected before 1975. In all cases, it can be seen that the equation fits the data well with the co-efficient of determination (r^2) ranging from 0.67 to 0.89 but staying between 0.68 and 0.85 for most years. This indicates that between 67% and 89% of the variation in the data is accounted for in the length weight relationship. It can be seen from Figure 3.5.1 that the slope varies somewhat between 2.90 and 3.58. The slope (b), intercept (a) and the co-efficient of determination of regression (r^2) for males and females separately are presented in Table 3.5.2 for 1980 – 1990. It can be seen that there is little difference between males and females in terms of slope or intercept. Thus there is not much difference in the length/weight relationship between males and females over a period accompanying wide fluctuations in mean length and mean weight at age.

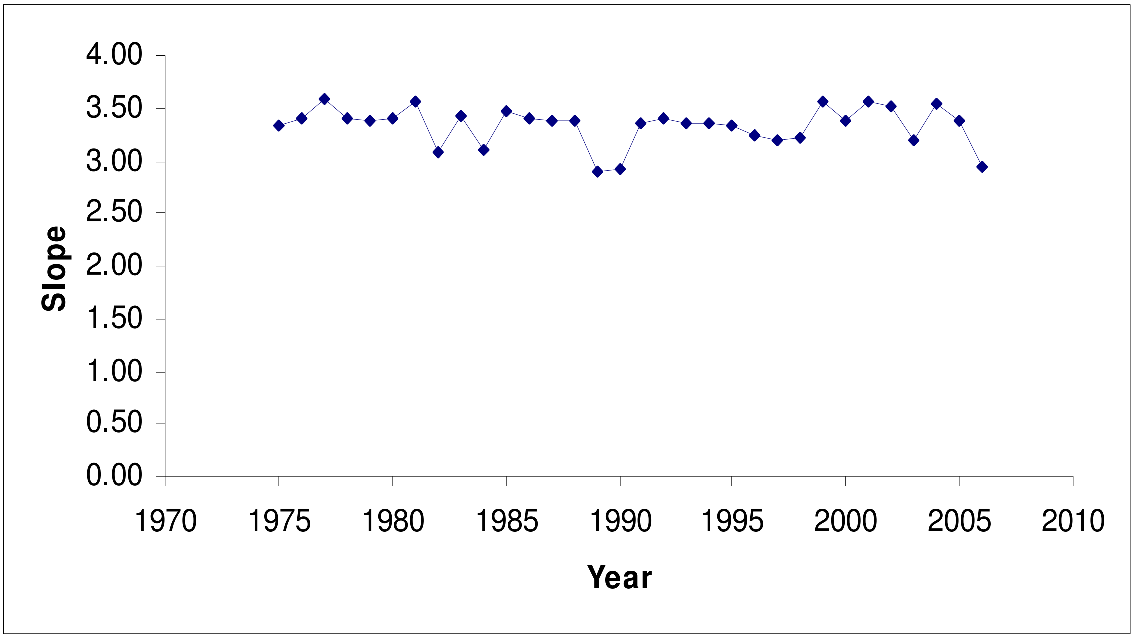
Fulton's condition factor displayed a decline over time for both dominant age groups (2 and 3 winter rings) and is seen in Figure 3.5.2. These declines were significant for 2 winter rings (F-statistic), $p < 0.001$, $r^2 = 0.508$, s.e. = 0.0002) and for 3 winter rings also (F-statistic), $p < 0.001$, $r^2 = 0.46$, s.e. = 0.0002). This suggests a decline in overall condition throughout the time series, with the 1999/2000 and 2002/2003 year classes displaying lowest K in the series.

Table 3.5.1 Length weight relationships (a, b, r^2) by year (q4 and q1 combined). Males and females combined

Year	Slope	Intercept	R^2
1975	3.33	-5.82	0.78
1976	3.41	-6.11	0.86
1977	3.58	-6.78	0.69
1978	3.39	-6.08	0.65
1979	3.39	-6.09	0.67
1980	3.40	-6.09	0.73
1981	3.57	-6.63	0.86
1982	3.08	-5.10	0.77
1983	3.42	-6.19	0.76
1984	3.11	-5.15	0.78
1985	3.46	-6.30	0.83
1986	3.40	-6.06	0.79
1987	3.38	-6.01	0.79
1988	3.37	-5.99	0.83
1989	2.90	-4.50	0.80
1990	2.91	-4.50	0.67
1991	3.35	-5.91	0.74
1992	3.40	-6.12	0.85
1993	3.35	-5.92	0.86
1994	3.36	-5.95	0.80
1995	3.33	-5.89	0.84
1996	3.25	-5.64	0.83
1997	3.19	-5.44	0.80
1998	3.21	-5.50	0.85
1999	3.56	-6.63	0.86
2000	3.39	-6.06	0.89
2001	3.57	-6.65	0.83
2002	3.52	-6.47	0.79
2003	3.20	-5.49	0.82
2004	3.54	-6.56	0.73
2005	3.39	-6.10	0.88
2006	2.94	-4.65	0.84

Table 3.5.2 Length weight relationships (a, b, r^2) for males and females separately

Sex	Year	Slope	Intercept	R^2
Male	1980 - 1990	3.31	-5.79	0.81
Female	1980 - 1990	3.23	-5.53	0.80



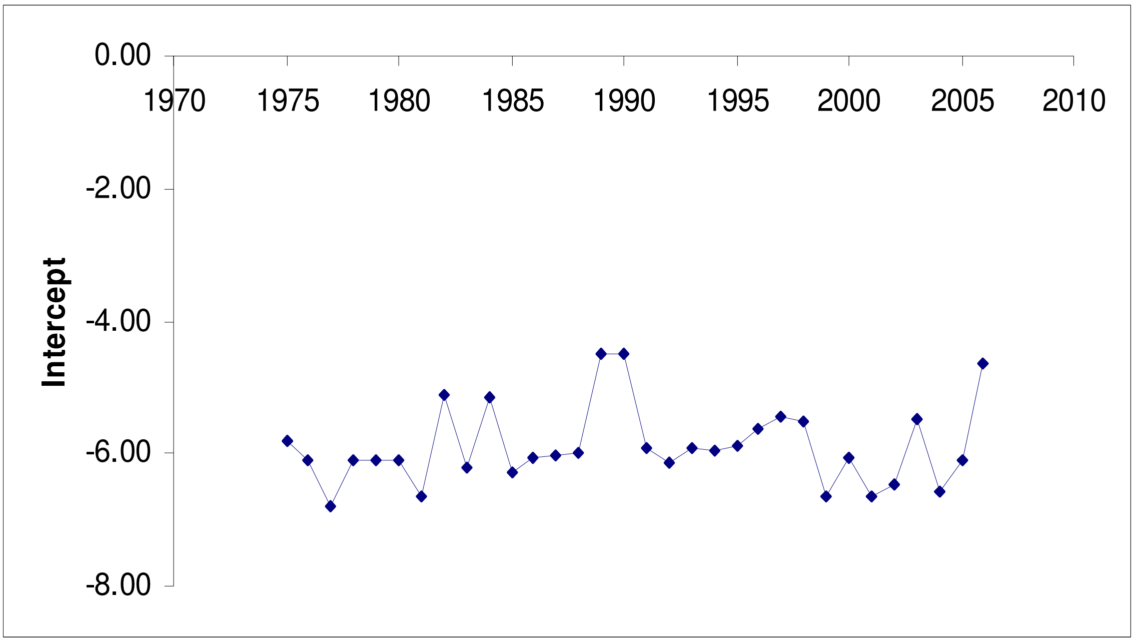


Figure 3.5.1 The slope and intercepts of the length weight relationships per year.

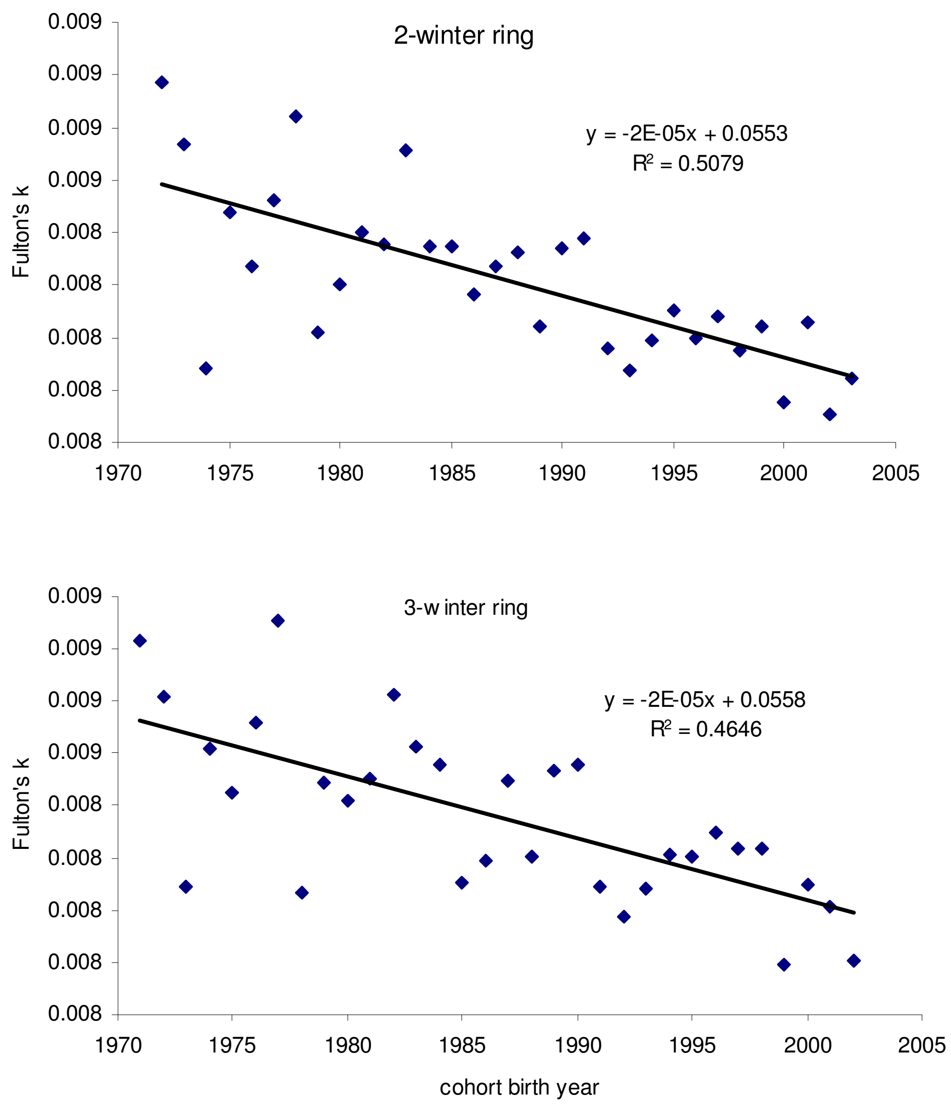


Figure 3.5.2 Trends over time in Fulton's condition factor (k) for the two dominant age groups in the population. Cohort birth date indicated by earlier year, thus 1974 = 1974/1975.

3.6 Maturity ogives by age

The percentage of fish mature by age (winter rings) from the reconstructed data is presented in Tables 3.6.1 and 3.6.2 for females and males respectively. The percentage of females mature at 1 winter ring is shown in Figure 3.6.1 (a) and the percentage of females mature at 2 and 3 winter rings are shown in Figure 3.6.1 (b). The percentage of males mature at 1 winter ring is shown in 3.6.2 (a) and the percentage of males mature at 2 and 3 winter rings are shown in Figure 3.6.2 (b). For females and males, it can be seen that full maturity is usually attained by 2 winter rings (3 year old). Wide fluctuations in the number of females and males reaching maturity at 1 winter-ring, (2 year olds) can be seen from year to year (Figs. 3.6.1a and 3.6.2a). This may depend on sampling location, for example if samples contained a lot of herring from Waterford Harbour (VIIaS) then you would expect a lot of small immature fish which have not yet recruited to the adult shoals.

It is interesting to note that the proportion mature at 1 winter ring is consistently higher in males (Table 3.6.2) than in females (Table 3.6.1). However, it must be noted that 1 winter ring herring are poorly represented in catches and therefore the relative portion mature from year to year may not be meaningful. It is likely that the catches of 1 winter ring herring are dominated by precocious, early maturing fish so that the proportion mature is higher than in the general population. There is no information on proportion mature for 0 winter ring (1 year olds) in these data as they are poorly represented in the catches. Also however, it is likely that 50% maturity probably occurs in the population between 0 winter ring and 2 winter ring. It is clear that 50% maturity in the catches occur between 0 winter ring and 1 winter ring.

The percentage mature at age for 2 winter ring fish may be more informative than 1 winter ring fish because this age group is fully selected by the fishery. It can be seen from Figure 3.6.1 (b) and 3.6.2 (b) that the lowest percentages were observed in the years 1978, 1979 and 2003. These observations are from the 1975/1976, 1976/1977 and 2000/2001 year classes respectively.

Table 3.6.1. Maturity ogive by age in winter rings for female Celtic Sea herring from re-constructed data

Year	0	1	2	3	4	5	6	7	8	9	10
1962		0.05	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1963		0.10	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1964		0.50	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1965		0.21	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1966		0.24	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1967		0.41	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1968		0.62	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1969		0.34	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1970		0.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1971		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1972		0.46	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1973		0.77	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1974		0.74	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1975	0.00	0.85	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1976	0.00	0.93	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1977		0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1978	0.00	0.81	0.95	0.96	1.00	1.00	1.00	1.00	1.00	1.00	
1979		0.23	0.85	0.98	1.00	1.00	1.00	1.00	1.00		
1980	0.02	0.81	0.99	0.98	1.00	1.00	1.00	1.00	1.00		
1981	0.00	0.53	0.99	1.00	1.00	1.00	1.00	1.00	1.00		
1982	0	0.84	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1983		0.64	0.99	1.00	1.00	1.00	1.00	1.00	1.00		
1984		0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1985		0.78	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1986		0.26	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1987		0.36	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1988		0.61	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1989		0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990		0.59	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1991		0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1992		0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00		
1993		0.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1994	0	0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1995		0.48	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	
1996		0.17	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1997		0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1998		0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1999		0.78	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	
2000		0.54	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
2001		0.48	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
2002		0.83	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
2003		0.24	0.96	0.98	0.97	0.98	1.00	1.00	1.00		
2004		0.49	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
2005		0.63	1.00	1.00	1.00	1.00	1.00	1.00			
2006		0.79	0.99	1.00	1.00	1.00	1.00	1.00	1.00		

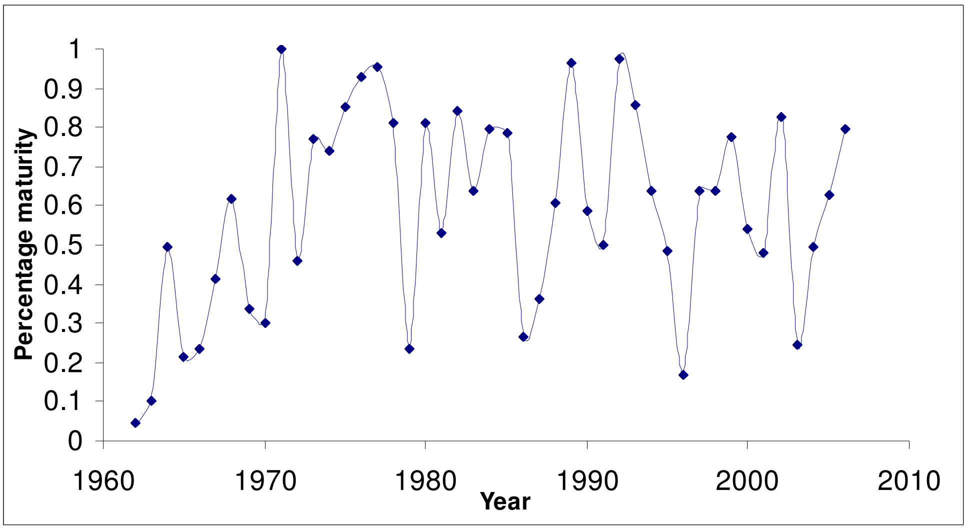


Figure 3.6.1 (a) Percentage maturity in females at winter ring 1

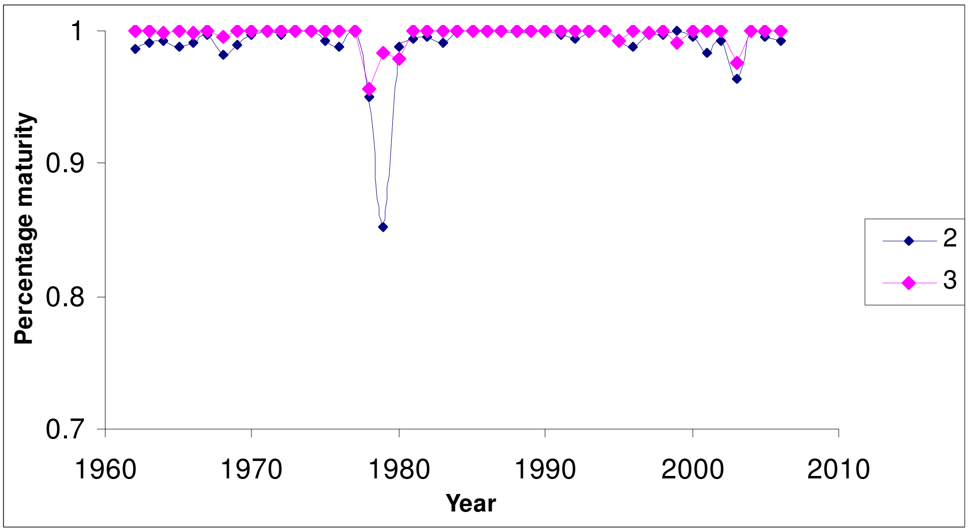


Figure 3.6.1 (b) Percentage maturity in females at winter ring 2 and winter ring 3

Table 3.6.2 Percentage maturity at age in winter rings for male Celtic Sea herring from reconstructed data.

Year	0	1	2	3	4	5	6	7	8	9	10
1962		0.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1963		0.30	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1964		0.84	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1965		0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1966		0.52	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1967		0.77	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1968		0.92	0.99	0.98	1.00	1.00	1.00	1.00	1.00	1.00	
1969		0.69	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1970		0.63	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1971		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1972		0.76	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1973		0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1974		0.93	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	
1975		0.96	0.99	1.00	0.98	1.00	1.00	1.00	1.00	1.00	
1976		0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1977		0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1978	0	1.00	0.94	0.96	0.94	1.00	1.00	1.00	1.00	1.00	
1979		0.61	0.89	0.98	1.00	1.00	1.00	1.00	1.00	1.00	
1980	0	0.86	0.99	0.97	0.99	1.00	1.00	1.00	1.00	1.00	
1981	0	0.71	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1982		0.91	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1983		0.41	0.99	1.00	1.00	1.00	1.00	1.00	1.00		
1984		0.47	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1985		0.73	1.00	1.00	1.00	1.00	1.00	1.00			
1986		0.69	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1987		0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1988		0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1989		0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1990		0.82	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1991		0.44	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1992		0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1993		0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1994	0	0.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
1995		0.64	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1996		0.64	0.99	1.00	1.00	1.00	1.00	1.00	1.00		1.00
1997		0.82	1.00	0.99	1.00	1.00	0.99	1.00	1.00		1.00
1998		0.58	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
1999		0.90	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
2000		0.81	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
2001		0.67	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
2002		0.97	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	
2003		0.58	0.94	0.97	0.98	0.98	0.86	1.00	1.00		
2004		0.74	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00
2005		0.75	0.99	1.00	1.00	1.00	1.00	1.00	1.00		
2006		0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

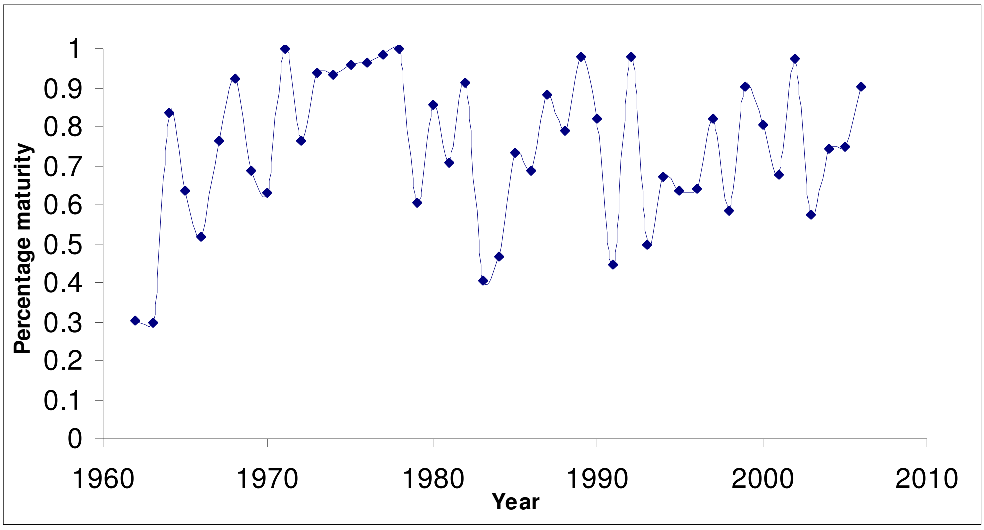


Figure 3.6.2 (a) Percentage maturity in males at winter ring 1

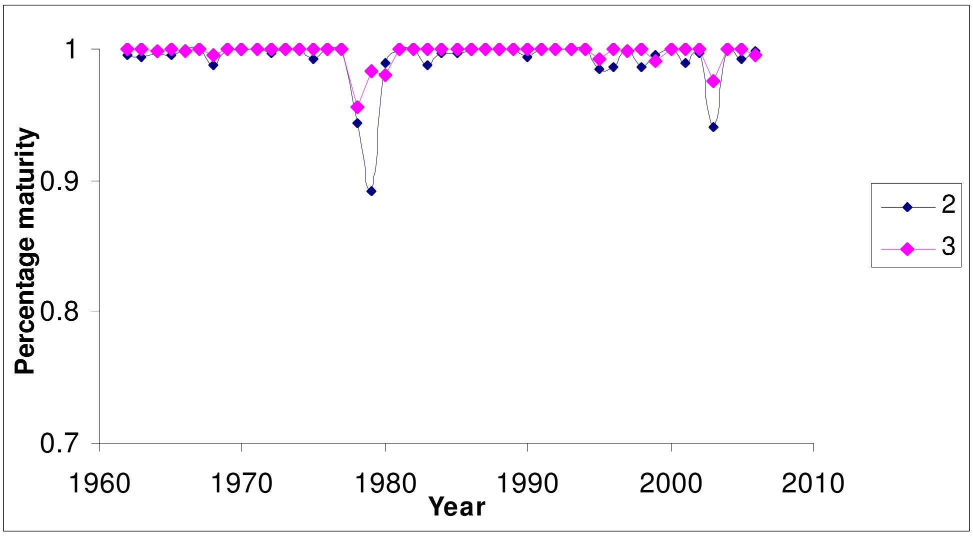


Figure 3.6.2 (b) Percentage maturity in males at winter ring 2 and winter ring 3.

3.7 Absolute Growth Increment

Mean length and mean weight data were taken from reconstructed data and arranged by year class.

The absolute growth rate length increment for each year interval was calculated per year class and is presented in Table 3.7.1. The fastest and slowest growing year classes for 1 - 2 winter rings are presented in Table 3.7.2 (a) and (b) respectively. It can be seen from these tables that the fastest growing year class in mean length was 1959 and the slowest growing year classes in mean length were 2001. It can also be seen from Table 3.7.2 that the fastest growing year class in mean length for 2-3 winter rings was 1963 and the slowest growing year class was 1973. For 3-4 winter rings the fastest year class was 1977 and the slowest year classes were 1993. The absolute growth rate in mean length for 1-2 winter rings, 2-3 winter rings, 3-4 winter rings and 2-5 winter rings (most abundant age groups) are shown in Figure 3.7.1. It can be seen that the growth rate varies slightly from year class to year class.

The weight increment was calculated per year class and is presented in Table 3.7.3. The fastest and slowest growing year classes for 1-2 winter rings are presented in Tables 3.7.4 (a) and (b) respectively. It can be seen from Table 3.7.3 that the fastest growing year class in mean weight was 1976 and the slowest growing year classes in mean weight were 2001, 1999 and 1985. Table 3.7.4 shows the 1979 year class as the fastest and the 1978 year class as the slowest for 2-3 winter rings. This table also shows the 1976 year class as the fastest and the 1977 year class as the slowest for 3-4 winter rings. The absolute growth rate in mean weight for 1-2 winter rings, 2-3 winter rings, 3-4 winter rings and 2-5 winter rings are shown in Figures 3.7.2 respectively. It can be seen that the growth rate varies slightly from year class to year class. The growth rate is lower for 2-3 winter rings in 2004 year class and for 3-4 winter rings in the 2003 year class.

The absolute growth rate in length and weight of each cohort for which information was available over the age interval of 2 to 5 winter rings. When these growth rates were regressed against cohort birth year, declining growth became apparent. These declines were highly significant, both for length (F-statistic, $p < 0.001$, $r^2 = 0.527$, s.e. =0.097) and weight (F-statistic, $p < 0.001$, $r^2 = 0.374$, s.e. =0.022). The decline is more marked for mean weight, because weight is a power function of length

There was no significant relationship between absolute growth rate I_m and year class strength, either in terms of length (F-statistic, $p = 0.43$, $r^2 = 0.016$, s.e. = 0.112) or weight (F-statistic, $p = 0.94$, $r^2 = 0.0004$, s.e.= 0.027).

Table 3.7.1 Absolute growth rate in mean length (cm) per year class. Each year class is defined by first year so 1974/1975 year class is indicated as 1974.

	Yearly Age interval								
Year	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**2-5**
1958			1.46	1.05	1.21	0.91	0.91	0.80	1.87
1959		1.93	1.05	1.32	0.99	1.00	0.89	0.76	1.66
1960			1.47	1.02	1.10	0.91	0.82	0.81	1.81
1961		1.55	1.40	1.22	1.06	0.92	0.82	0.75	1.85
1962		1.43	1.40	1.31	1.02	0.88	0.83	0.97	1.88
1963		1.46	1.50	1.10	0.99	0.85	0.93	0.81	1.82
1964		1.52	1.25	1.11	1.06	0.85	0.97	0.85	1.69
1965		1.53	1.34	1.09	1.04	0.97	0.79	1.06	1.73
1966		1.57	1.28	1.10	1.03	0.89	0.77	1.03	1.68
1967		1.45	1.36	1.10	1.01	0.93	0.82	0.86	1.73
1968		1.41	1.31	1.06	1.12	0.88	0.89	0.68	1.73
1969		1.55	1.23	1.21	0.95	0.99	0.62	1.05	1.68
1970		1.59	1.28	1.05	1.05	0.87	0.65	0.88	1.67
1971		1.48	1.26	1.12	1.05	0.58	0.86	0.75	1.69
1972		1.66	1.25	0.96	0.76	1.02	0.82	0.97	1.44
1973		1.40	0.60	1.17	1.03	1.01	0.89	1.06	1.35
1974	2.00	1.36	1.25	1.13	0.99	0.97	1.09	0.69	1.66
1975	2.07	1.50	1.29	0.95	1.08	0.98	0.55	1.25	1.64
1976	2.13	1.53	1.04	1.13	1.21	0.77	-0.04	1.29	1.67
1977	2.01	1.36	1.27	1.41	0.92	0.86	0.81	1.01	1.81
1978	1.99	1.47	1.35	1.03	1.04	0.85	-0.03	1.40	1.71
1979	1.63	1.53	1.00	1.25	0.93	0.91	1.02	0.71	1.56
1980	2.17	1.55	1.45	0.96	0.99	0.87	0.68	1.04	1.71
1981	2.24	1.39	1.24	1.04	1.09	0.80	0.85	1.00	1.66
1982	2.06	1.14	1.25	1.18	0.94	0.91	0.90	1.01	1.67
1983	1.76	1.56	1.29	1.05	0.94	0.94	0.67	1.03	1.62
1984	2.18	1.43	1.21	1.04	0.84	1.00	0.79	0.92	1.50
1985	2.16	1.26	1.34	0.99	0.97	0.88	0.85	0.96	1.64
1986		1.52	1.19	1.04	0.98	0.91	0.86	0.97	1.56
1987		1.61	1.23	1.12	0.97	0.77	1.05	0.85	1.63
1988	2.15	1.40	1.27	0.98	1.07	0.82	0.86	1.03	1.64
1989		1.39	1.13	1.19	1.01	0.81	1.03	0.80	1.63
1990		1.52	1.28	1.13	0.96	0.98	0.73	0.86	1.67
1991	2.15	1.40	1.37	1.07	0.98	0.77	0.87	0.78	1.71
1992	1.72	1.49	1.22	1.02	0.93	0.81	0.89	1.05	1.55
1993		1.53	1.26	0.79	1.03	0.88	0.99	0.89	1.51
1994	1.87	1.42	1.14	1.11	1.04	0.86	0.72	0.92	1.61
1995		1.44	1.33	1.08	0.99	0.79	0.43	1.05	1.69
1996		1.45	1.33	1.11	0.78	0.75	0.75	1.63	1.61
1997		1.35	1.25	0.92	0.90	0.57	1.38	0.33	1.49
1998		1.26	1.17	0.92	0.96	0.88	1.13		1.47
1999		1.19	1.21	0.99	0.95	0.98			1.53
2000		1.31	1.18	1.11	1.03				1.62
2001		1.00	1.31	1.11					
2002	1.56	1.46	1.18						
2003		1.35							

Table 3.7.2 (a) Fastest growing year classes in total mean length, for several combinations of age groups, spanning the most abundant ages in the catches.

Rank	1-2 ringer	2-3 ringer	3-4 ringer	2-5 ringer
1	1959	1963	1977	1962
2	1972	1960	1959	1958
3	1987	1958	1962	1961
4	1970	1980	1979	1963
5	1966	1962	1961	1977
6	1983	1961	1969	1960
7	1980	1991	1989	1968
8	1961	1967	1982	1965
9	1969	1978	1973	1967
10	1993	1965	1976	1980

Table 3.7.2 (b) Slowest growing year classes in total mean length, for several combinations of age groups, spanning the most abundant ages in the catches.

Rank	1-2 ringer	2-3 ringer	3-4 ringer	2-5 ringer
1	2001	1973	1993	1973
2	1982	1979	1997	1972
3	1999	1976	1998	1998
4	1985	1959	1975	1997
5	1998	1989	1972	1984
6	2000	1994	1980	1993
7	2003	1998	1988	1999
8	1997	2000	1985	1992
9	1974	2002	1999	1979
10	1977	1986	1960	1986

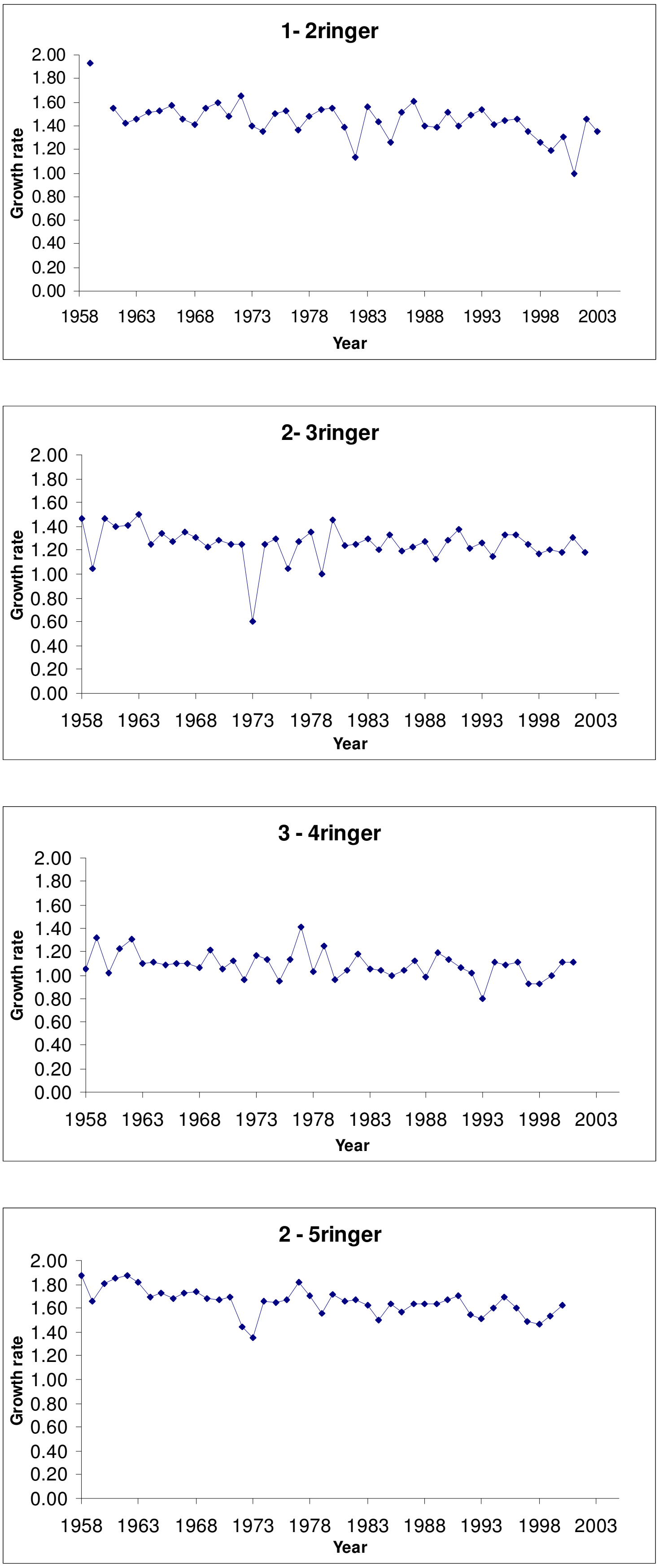


Figure 3.7.1 Absolute growth rate in mean total length (cm) for 1-2, 2-3, 3-4 and 2-5 winter rings respectively, by year class. Please note that 1974 = 1974/1975 year class.

Table 3.7.3 Absolute growth rate in mean total weight (g) per year class. Each year class is defined by first year so 1974/1975 year class is indicated as 1974.

	Yearly age intervals								
Year	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**2-5**
1974	0.73	0.71	0.72	0.70	0.71	0.71	0.67	0.72	0.74
1975	0.73	0.72	0.70	0.71	0.72	0.68	0.69	0.71	0.74
1976	0.73	0.71	0.71	0.72	0.68	0.71	0.69	0.71	0.73
1977	0.73	0.72	0.72	0.69	0.71	0.69	0.69	0.73	0.73
1978	0.72	0.72	0.69	0.71	0.70	0.71	0.71	0.69	0.72
1979	0.73	0.71	0.72	0.70	0.71	0.70	0.69	0.71	0.74
1980	0.73	0.71	0.71	0.70	0.71	0.69	0.70	0.69	0.73
1981	0.73	0.71	0.71	0.71	0.70	0.70	0.69	0.70	0.73
1982	0.72	0.71	0.71	0.70	0.70	0.69	0.69	0.71	0.73
1983	0.73	0.72	0.71	0.70	0.69	0.70	0.70	0.70	0.71
1984	0.73	0.70	0.71	0.69	0.70	0.70	0.69	0.70	0.72
1985		0.71	0.70	0.70	0.70	0.70	0.70	0.70	0.72
1986		0.71	0.71	0.71	0.70	0.70	0.70	0.69	0.72
1987	0.73	0.71	0.71	0.70	0.71	0.70	0.69	0.70	0.73
1988		0.71	0.70	0.71	0.70	0.69	0.70	0.70	0.73
1989		0.71	0.71	0.70	0.70	0.70	0.69	0.70	0.72
1990	0.72	0.71	0.71	0.70	0.70	0.70	0.70	0.70	0.72
1991	0.72	0.71	0.70	0.70	0.70	0.70	0.70	0.70	0.71
1992		0.71	0.71	0.70	0.70	0.70	0.70	0.70	0.72
1993	0.72	0.71	0.70	0.70	0.70	0.70	0.70	0.70	0.72
1994		0.71	0.71	0.70	0.70	0.70	0.69	0.69	0.73
1995		0.71	0.71	0.70	0.70	0.70	0.69	0.74	0.72
1996		0.71	0.71	0.70	0.70	0.68	0.72	0.68	0.72
1997		0.71	0.70	0.70	0.69	0.70	0.70	0.68	0.71
1998		0.70	0.71	0.70	0.70	0.70	0.69	0.61	0.72
1999		0.71	0.70	0.70	0.70	0.69	0.61		0.72
2000		0.70	0.71	0.70	0.69	0.62			0.72
2001	0.70	0.71	0.70	0.70	0.62				
2002		0.71	0.70						
2003		0.71							

Table 3.7.4 (a) Fastest year classes in mean total weight (g) for several combinations of age groups, spanning the most abundant ages in the catches.

Rank	1-2 ring	2-3 ring	3-4 ring	2-5 ring
1	1975	1979	1976	1975
2	1978	1977	1978	1974
3	1977	1974	1981	1979
4	1983	1976	1975	1980
5	1982	1982	1988	1977
6	1985	1990	1986	1976
7	1986	1984	1989	1981
8	1979	1989	1995	1982
9	1991	1994	1980	1994
10	1990	1987	1999	1987

Table 3.7.4 (b) Slowest year classes in mean total weight (g) for several combinations of age groups, spanning the most abundant ages in the catches.

Rank	1-2 ring	2-3 ring	3-4 ring	2-5 ring
1	2000	1978	1977	1997
2	1998	1999	1984	1983
3	1984	1988	1998	1991
4	1981	1975	1992	1998
5	2002	1985	2001	2000
6	1996	1991	1987	1999
7	1997	2001	1990	1992
8	1999	2002	1974	1978
9	2003	1997	1979	1984
10	1988	1993	1997	1996

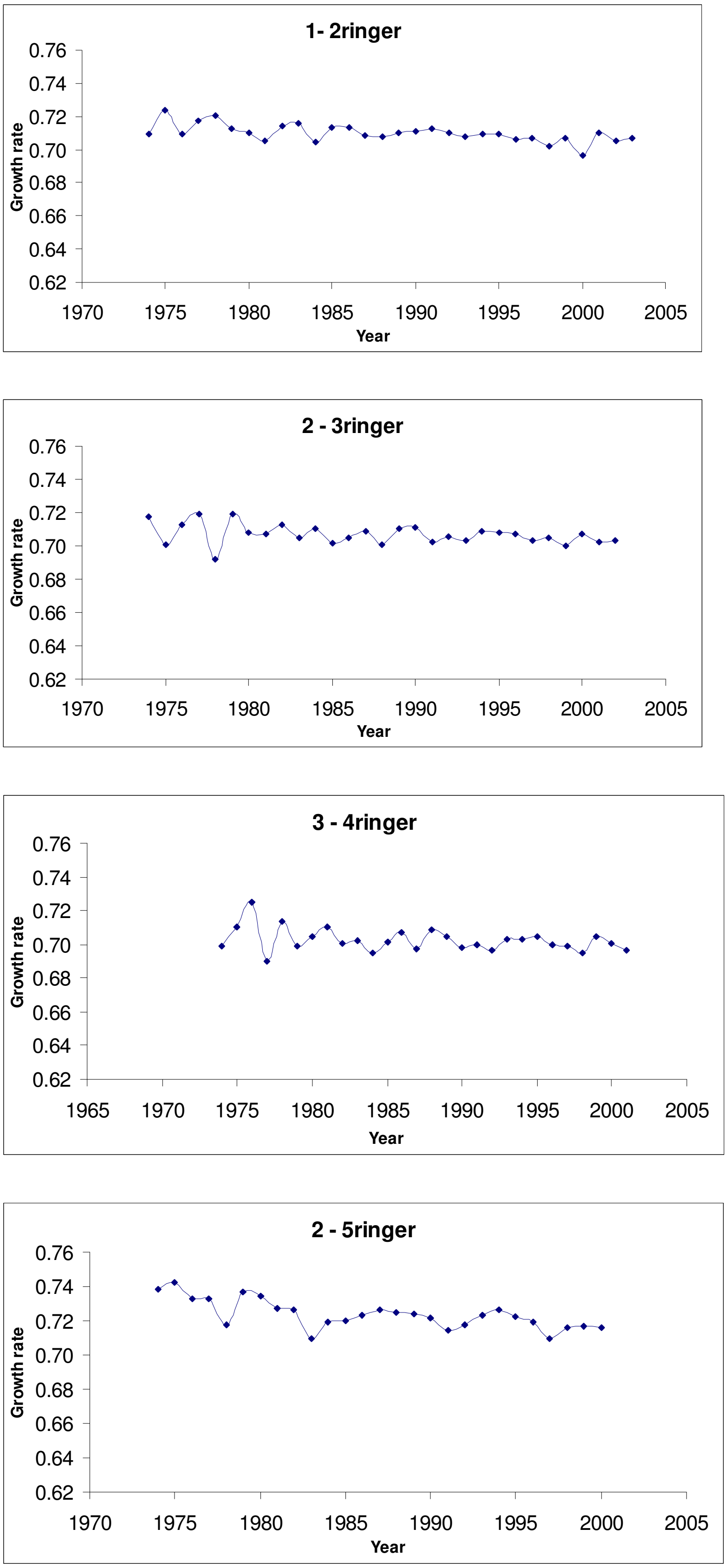


Figure 3.7.2 Absolute growth rate in mean total weight (g) for 1-2, 2-3, 3-4 and 2-5 winter rings respectively, by year class. Please note that 1974 = 1974/1975 year class

3.8 Environment of the Celtic Sea

Sea Surface temperature

Sea surface temperature means per year for the Celtic Sea were taken from a grid dataset (Second Hadley Centre Sea Surface Temperature dataset (HadSST2)). Celtic Sea SST data for September are shown in Figure 3.8.1 from 1970 to 2004. September was selected because it was one of the warmest months over the time series, and is considered a good index of temperature throughout the summer. The temperature varies only very slightly from 1970 to 1984. It then becomes more variable with a strong increase from 1994 onwards.

Irish Sea SST data are shown in Figure 3.8.2 from 1970 to 2004. The same trend is apparent as in the Celtic Sea, with a marked increase since 1994.

Calanus abundance

The abundance over time of *Calanus helgolandicus* and *Calanus finmarchicus* are displayed in Figures 3.8.3 to 3.8.8 by ICES Division and for the months of May and September. The number of samples collected is also shown. *Calanus helgolandicus* shows a higher abundance than *Calanus finmarchicus* for all Divisions in both May and September. It is difficult to detect trends in abundance over time, because of large variations in sampling effort (Section 2.10)

North Atlantic Oscillation

The North Atlantic Oscillation (NAO) winter index is taken from the Climate Research Unit (CRU) at http://www.cru.uea.ac.uk/cru/data/nao.htm and presented in Figure 3.8.9. The winter index fluctuates between positive and negative phases until 1989. The year 1989 is the year with the most positive value and it stayed in the positive phase until 1996.

Product Moment Correlation

The Product Moment Correlation coefficients, and their significance levels, between the environmental parameters (North Atlantic Oscillation, sea surface temperature, the abundance of *Calanus finmarchicus* and *Calanus helgolandicus*), the Herring Assessment Working Group parameters (Spawning Stock Biomass (SSB), Fishing Mortality (F) and Recruitment (R)) and biological parameters (absolute growth rate in mean length and mean weight, mean length at age, mean weight at age and condition factor) were investigated and results are shown in Tables 3.8.1 a, b, c and d. Figure 3.8.10 shows a range of significant correlations between biological and environmental variables. All the Product Moment Correlation coefficients were quite low with the maximum value being 0.50. This indicates that at best the Product Moment Correlations were modest, weak, or else very weak.

Mean length at age (2 and 3 winter rings) showed significant but weak negative correlations with sea surface temperature in both the Irish and Celtic Seas. This indicates that as sea surface temperature increases the mean length declined. Since the SST in both seas shows the same trend (Figure 3.8.1 and 3.8.2) it is not surprising that both show similar correlations with mean length.

A significant positive correlation between mean length at age and mean weight at age in VIIg in September was found with *C. helgolandicus.* The same relationship was found to be significant with *C. finmarchicus* but only for mean weight at age (2 ringer). Mean weight at age was found to have positive correlations with the abundance of *Calanus finmarchicus* in the Irish Sea but only for the month of May. This suggests that herring in this area attained larger weight in years where these prey species were more abundant. Very few correlations between *Calanus finmarchicus* abundance and mean size were significant and there were no significant correlations between *C. helgolandicus* and mean size.

Absolute growth rate in mean length for 2-5 winter rings was found to have a highly significant, modest and negative correlation with NAO in January. Absolute growth rate in mean weight did not show a significant correlation with NAO but it must be noted that the time series for mean weight was shorter.

There was a significant positive correlation found between Fulton's condition factor and *Calanus finmarchicus* for both 2 and 3 ringers. This points towards better fish condition when prey abundance is higher. However Fulton's Condition Factor shows a significant, negative and weak correlation with sea surface temperature in both the Irish and Celtic Sea. This indicates that high temperatures are associated with a low condition factor. There were no other significant correlations found between the environmental and biological variables.

There was a significant, positive and modest correlation found between Spawning Stock Biomass (SSB) and absolute growth rate in mean weight. SSB also had a significant but weak correlation with mean length at age by year class for 2 ringer. There was a significant, negative and modest correlation found between Fishing Mortality (F) and absolute growth rate in mean length. F also had a significant, positive but weak correlation with raw mean weight at age for 3 ringer.

A summary of the biological and environmental parameters are shown in Table 3.8.2. This shows the main trends in the biological and environmental variables, along with the main outputs from the stock assessment. The results of the latest stock assessment (Anon, 2009) showing Fishing mortality (F) (mean over 2-5 ringers), spawning stock biomass (SSB), catch (C) and recruitment (R) (estimated numbers of 1-ringers) are presented in Figure 3.8.11.

Mean length and mean weight for 2 and 3 winter rings were plotted with the spawning stock biomass in Figures 3.8.12 and 3.8.13. The maximum mean length was observed when stock was low in the 1970s but mean length is presently at the lowest in the time series and the stock size is as low as it was in the 1970s. This trend is apparent in mean weight also. This suggests that density dependant growth is not a factor at present. It appears from Figure 3.8.14 which shows the absolute growth rate in mean length and mean weight for 2-5 winter rings that growth rate decreased since the 1960s when the stock size was high and growth rate was high. When the stock size was declining, due to increased F and reduced recruitment (Figure 3.8.11), in the 1970s, growth rate declined markedly. During the period of the stock collapse, the growth rate improved somewhat, and seems to have declined again during the period when the stock recovered. The present situation is less clear, because the recent year classes are not fully observed in the sampling data. However it appears from recent mean length and mean weight values that, unlike the situation in the 1970s, increased growth has not compensated for the low stock size.

The fishing mortality for the Celtic Sea stock from 1958 to 2007 is presented in Figures 3.8.15 and 3.8.16. The mean lengths and mean weights for 2 and 3 winter rings are plotted for comparison in Figure 3.8.15 and the growth increment (2-3 winter rings and 3-4 winter rings) in mean length and mean weight is plotted in Figure 3.8.16. When fishing mortality was at its highest point in the mid 1980s, mean lengths, mean weights and the growth rate in mean length and mean weight were decreasing.

Spawning stock biomass and fishing mortality are presented with percentage maturity in 1 ringer females and males in Figures 3.8.17 and 3.8.18 respectively. Spawning stock biomass decreased from late 1960s to the early 1980s. SSB then increased until the late 1980s and has decreased thereafter. The percentage maturity for 1 ringer females and males fluctuated greatly over the years presenting the lowest percentages in 1962 and 1963 and the highest percentages in 1971.

Recruitment is shown in Figure 3.8.19 with mean length and mean weight for 2 and 3 winter rings. It is also plotted with growth rate (2-3 winter rings and 3-4 winter rings) in mean length and mean weight in Figure 3.8.20. It can be seen that recruitment has declined sine the late 1980s.

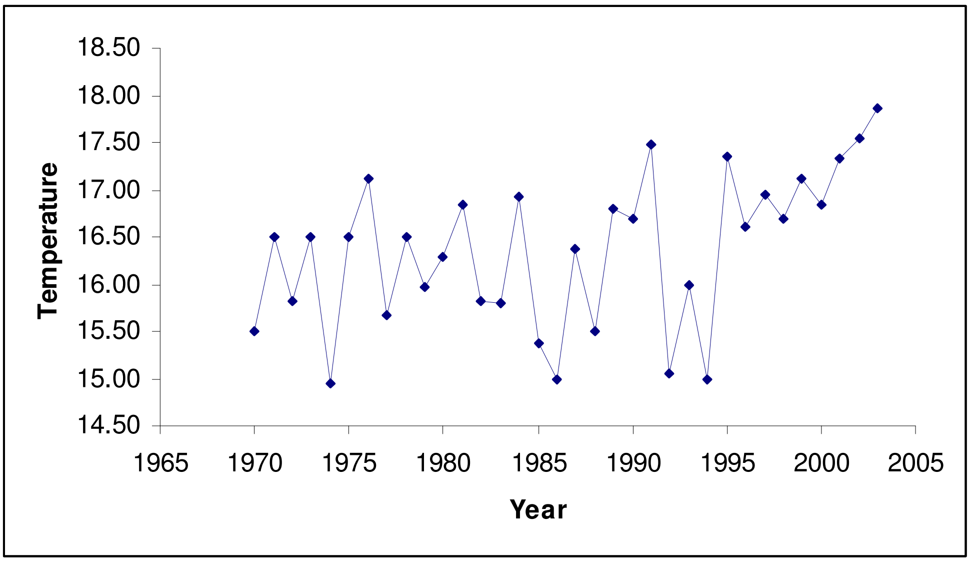


Figure 3.8.1 Sea Surface Temperature in °C for Celtic Sea from 1970/1971 to 2003/2004, for month of September.

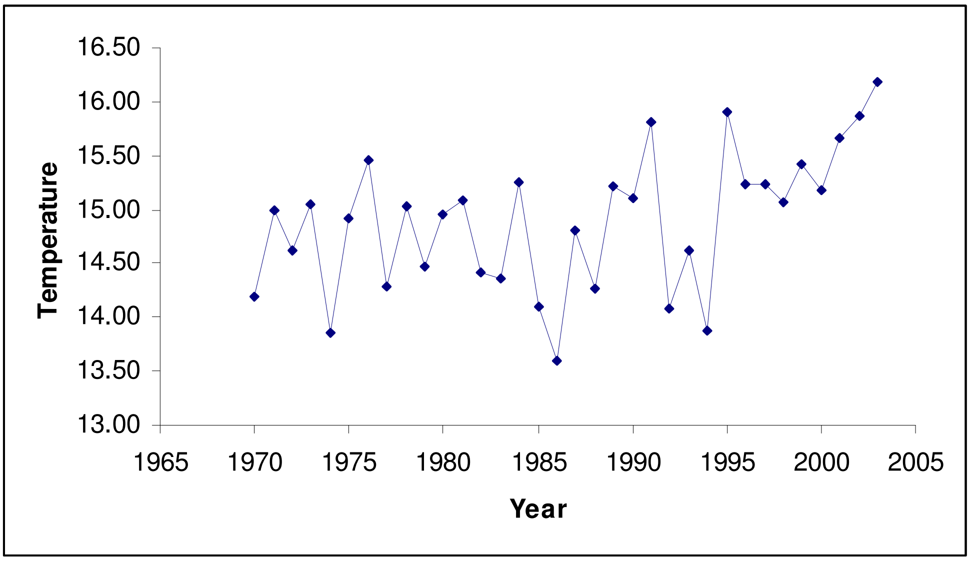


Figure 3.8.2 Sea Surface Temperature in °C for Irish Sea from 1970/1971 to 2003/2004, for month of September.

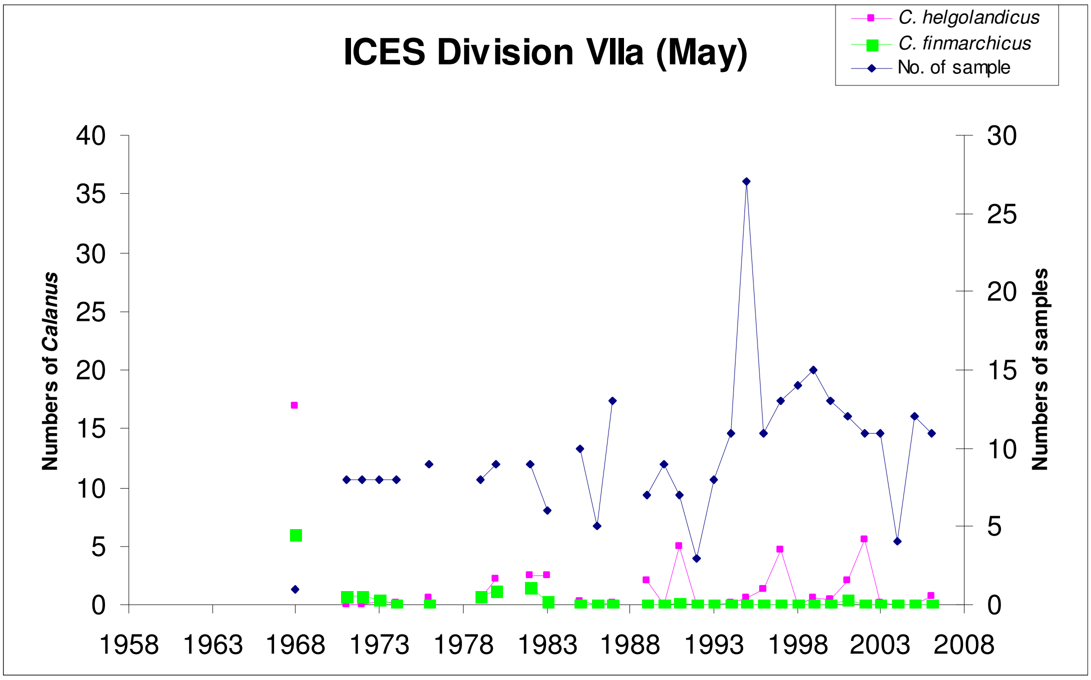


Figure 3.8.3 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus* and number of samples collected over time from ICES Division VIIa (May) from CPR data.

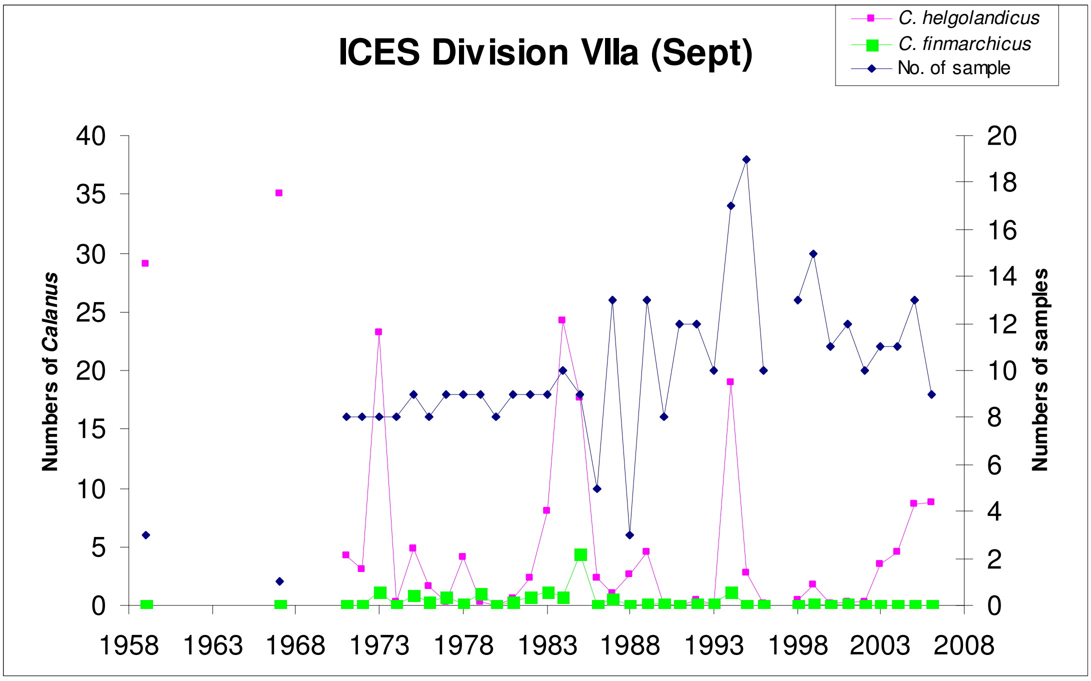


Figure 3.8.4 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus* and number of samples collected over time from ICES Division VIIa (Sept) from CPR data.

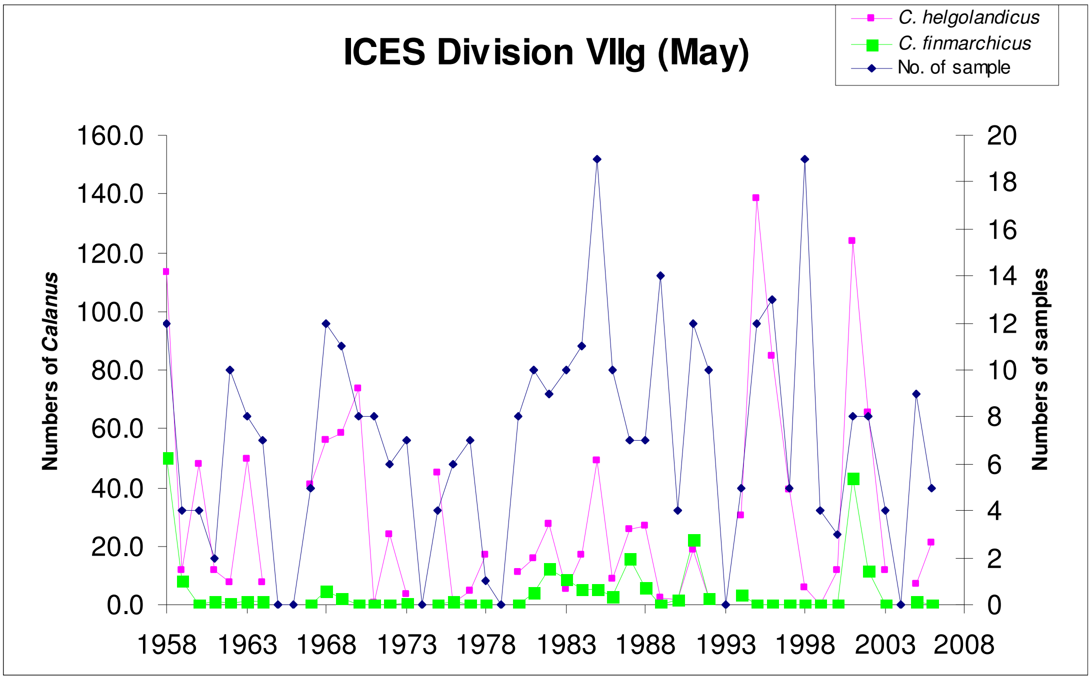


Figure 3.8.5 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus* and number of samples collected over time from ICES Division VIIg (May) from CPR data.

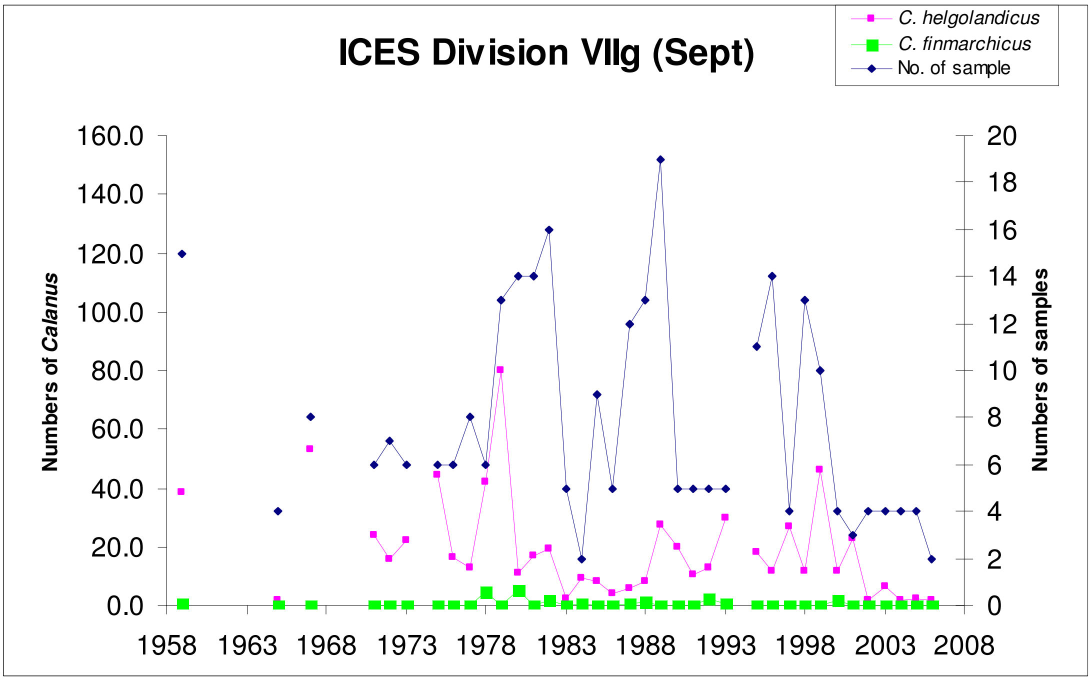


Figure 3.8.6 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus* and number of samples collected over time from ICES Division VIIg (Sept) from CPR data.

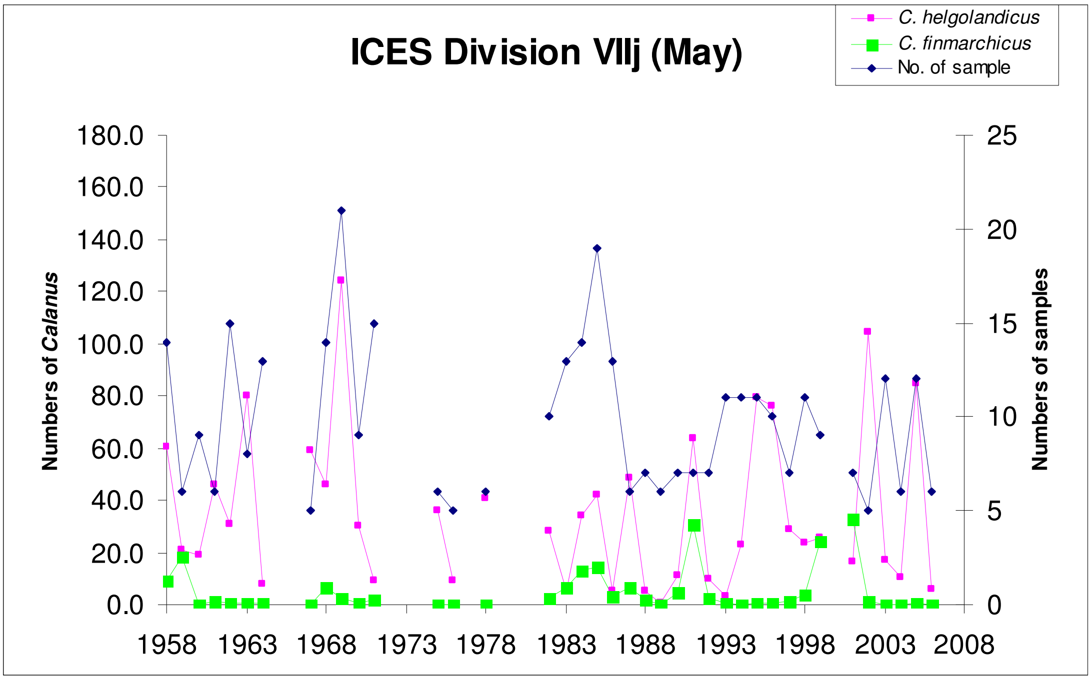


Figure 3.8.7 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus* and number of samples collected over time from ICES Division VIIj (May) from CPR data.

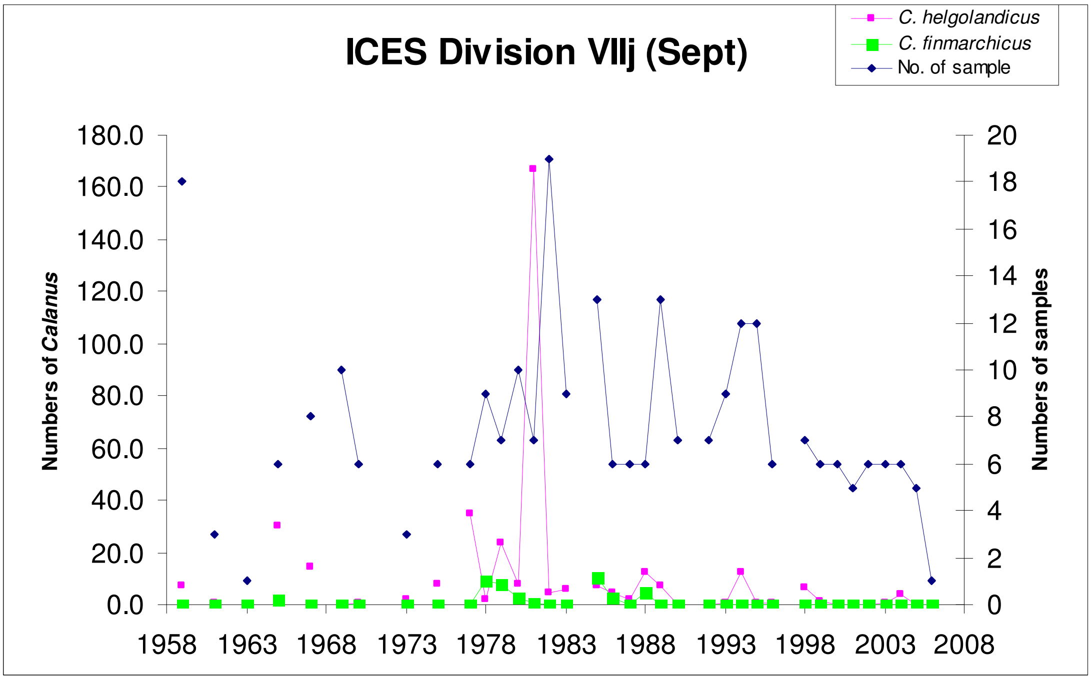


Figure 3.8.8 Abundance of *Calanus finmarchicus* and *Calanus helgolandicus* and number of samples collected over time from ICES Division VIIj (Sept) from CPR data.

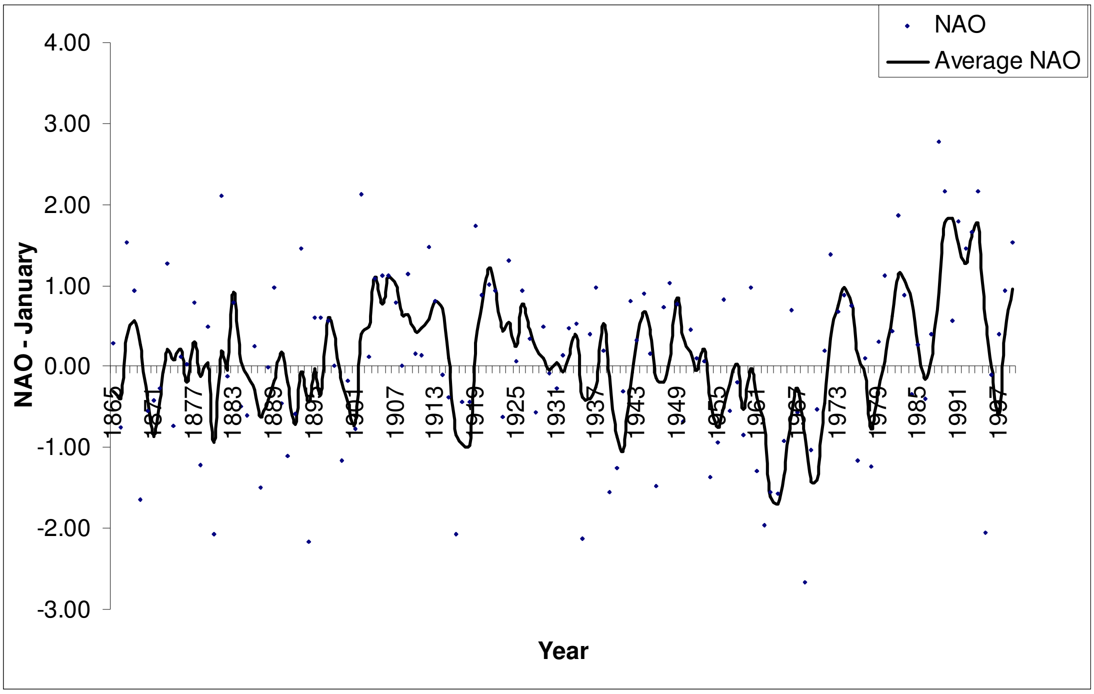


Figure 3.8.9 NAO Hurrell winter index with a 3 year moving mean smoother applied obtained from Climate Research Unit.

Table 3.8.1 (a) Product Moment Correlation coefficients r and significance levels between NAO (January) and SST (Irish and Celtic Sea) with various biological variables. Sample size (n) and degrees of freedom (df) indicated. Note year class shows correlations conducted for the birth year.

Environmental variable	Month	Biological variable		Ages	Years Range	n	Corr.	df	Sig
NAO	January	Absolute Growth Rate in MW		2/5	1969-1999	31	-0.321	29	NS
NAO	January	Absolute Growth Rate in ML		2/5	1958-1999	42	-0.442	40	0.01
NAO	January	Raw mean length at age	year class	2	1960-1999	40	-0.287	38	NS
NAO	January	Raw mean length at age	year class	3	1960-1999	40	-0.400	38	0.05
NAO	January	Raw mean weight at age	year class	2	1975-1999	25	-0.2226	23	NS
NAO	January	Raw mean weight at age	year class	3	1975-1999	25	-0.28301	23	NS
NAO	January	Raw mean length at age		2	1960-1999	40	-0.219	38	NS
NAO	January	Raw mean length at age		3	1960-1999	40	-0.223	38	NS
NAO	January	Raw mean weight at age		2	1975-1999	25	-0.291	23	NS
NAO	January	Raw mean weight at age		3	1975-1999	25	-0.218	23	NS
NAO	January	Fulton's condition factor		2	1972-1999	28	-0.151	26	NS
NAO	January	Fulton's condition factor		3	1971-1999	29	-0.214	27	NS
SST Irish sea	September	Absolute Growth Rate in MW		2/5	1970-2000	31	-0.180	29	NS
SST Irish sea	September	Absolute Growth Rate in ML		2/5	1970-2000	31	-0.003	29	NS
SST Irish sea	September	Raw mean length at age	year class	2	1970-2003	34	-0.374	32	0.05
SST Irish sea	September	Raw mean length at age	year class	3	1970-2002	33	-0.367	31	0.05
SST Irish sea	September	Raw mean weight at age	year class	2	1975-2003	29	-0.33571	27	NS
SST Irish sea	September	Raw mean weight at age	year class	3	1975-2002	28	-0.29051	26	NS
SST Irish sea	September	Raw mean length at age		2	1970-2003	34	-0.448	32	0.05
SST Irish sea	September	Raw mean length at age		3	1970-2003	34	-0.464	32	0.01
SST Irish sea	September	Raw mean weight at age		2	1975-2003	29	-0.378	27	0.05
SST Irish sea	September	Raw mean weight at age		3	1975-2003	29	-0.406	27	0.05
SST Irish sea	September	Fulton's condition factor		2	1972-2003	32	-0.357	30	0.05
SST Irish sea	September	Fulton's condition factor		3	1971-2002	32	-0.319	30	NS
SST Cetic Sea	September	Absolute Growth Rate in MW		2/5	1970-2000	31	-0.175	29	NS
SST Cetic Sea	September	Absolute Growth Rate in ML		2/5	1970-2000	31	-0.011	29	NS
SST Cetic Sea	September	Raw mean length at age	year class	2	1970-2003	34	-0.42712	32	0.05
SST Cetic Sea	September	Raw mean length at age	year class	3	1970-2002	33	-0.37484	31	0.05
SST Cetic Sea	September	Raw mean weight at age	year class	2	1975-2003	29	-0.31981	27	NS
SST Cetic Sea	September	Raw mean weight at age	year class	3	1975-2002	28	-0.2614	26	NS
SST Cetic Sea	September	Raw mean length at age		2	1975-2003	29	-0.338	27	NS
SST Cetic Sea	September	Raw mean length at age		3	1975-2003	29	-0.355	27	NS
SST Cetic Sea	September	Raw mean weight at age		2	1970-2003	34	-0.435	32	0.05
SST Cetic Sea	September	Raw mean weight at age		3	1970-2003	34	-0.435	32	0.05
SST Cetic Sea	September	Fulton's condition factor		2	1972-2003	32	-0.369	30	0.05
SST Cetic Sea	September	Fulton's condition factor		3	1971-2002	32	-0.319	30	NS

Table 3.8.1 (b) Product Moment Correlation coefficients (r) and significance levels between *Calanus helgolandicus* abundance in VIIa and VIIg and various biological variables. Sample size (n) and degrees of freedom (df) indicated. Note year class shows correlations conducted for the birth year.

Environmental variable	Month	Biological variable		Ages	Years Range	n	Corr.	df	Sig
VIIa	May	Absolute Growth Rate in MW		2/5	1971-2000	24	-0.275	22	NS
VIIa	May	Absolute Growth Rate in ML		2/5	1968-2000	25	0.348	23	NS
VIIa	May	Raw mean length at age	year class	2	1968-2003	28	0.082	26	NS
VIIa	May	Raw mean length at age	year class	3	1968-2002	27	0.046	25	NS
VIIa	May	Raw mean weight at age	year class	2	1976-2003	23	0.03199	21	NS
VIIa	May	Raw mean weight at age	year class	3	1976-2002	22	-0.16288	20	NS
VIIa	May	Raw mean length at age		2	1968-2006	31	0.113	29	NS
VIIa	May	Raw mean length at age		3	1968-2006	31	0.099	29	NS
VIIa	May	Raw mean weight at age		2	1976-2006	26	-0.011	24	NS
VIIa	May	Raw mean weight at age		3	1976-2006	26	-0.023	24	NS
VIIa	May	Fulton's condition factor		2	1972-2003	26	-0.169	24	NS
VIIa	May	Fulton's condition factor		3	1971-2002	26	-0.291	24	NS
VIIa	September	Absolute Growth Rate in MW		2/5	1971-2000	29	-0.054	27	NS
VIIa	September	Absolute Growth Rate in ML		2/5	1959-2000	31	-0.120	29	NS
VIIa	September	Raw mean length at age	year class	2	1967-2003	33	0.176	31	NS
VIIa	September	Raw mean length at age	year class	3	1967-2002	32	0.221	30	NS
VIIa	September	Raw mean weight at age	year class	2	1975-2003	28	-0.005	26	NS
VIIa	September	Raw mean weight at age	year class	3	1975-2002	27	0.025	25	NS
VIIa	September	Raw mean length at age		2	1967-2006	36	0.086	34	NS
VIIa	September	Raw mean length at age		3	1967-2006	36	0.122	34	NS
VIIa	September	Raw mean weight at age		2	1975-2006	31	-0.042	29	NS
VIIa	September	Raw mean weight at age		3	1975-2006	31	0.024	29	NS
VIIa	September	Fulton's condition factor		2	1972-2003	31	0.151	29	NS
VIIa	September	Fulton's condition factor		3	1971-2002	31	0.071	29	NS
VIIg	May	Absolute Growth Rate in MW		2/5	1969-2000	29	0.235	27	NS
VIIg	May	Absolute Growth Rate in ML		2/5	1958-2000	38	0.265	36	NS
VIIg	May	Raw mean length at age	year class	2	1960-2003	39	-0.060	37	NS
VIIg	May	Raw mean length at age	year class	3	1960-2002	38	-0.121	36	NS
VIIg	May	Raw mean weight at age	year class	2	1975-2003	27	-0.203	25	NS
VIIg	May	Raw mean weight at age	year class	3	1975-2002	26	-0.276	24	NS
VIIg	May	Raw mean length at age		2	1960-2006	41	-0.176	39	NS
VIIg	May	Raw mean length at age		3	1960-2006	41	-0.135	39	NS
VIIg	May	Raw mean weight at age		2	1975-2006	29	-0.230	27	NS
VIIg	May	Raw mean weight at age		3	1975-2006	29	-0.235	27	NS
VIIg	May	Fulton's condition factor		2	1972-2003	29	-0.187	27	NS
VIIg	May	Fulton's condition factor		3	1971-2002	29	-0.307	27	NS
VIIg	September	Absolute Growth Rate in MW		2/5	1971-2000	28	0.217	26	NS
VIIg	September	Absolute Growth Rate in ML		2/5	1959-2000	31	-0.051	29	NS
VIIg	September	Raw mean length at age	year class	2	1965-2003	33	0.250	31	NS
VIIg	September	Raw mean length at age	year class	3	1965-2002	32	0.257	30	NS
VIIg	September	Raw mean weight at age	year class	2	1975-2003	28	0.260	26	NS
VIIg	September	Raw mean weight at age	year class	3	1975-2002	27	0.220	25	NS
VIIg	September	Raw mean length at age		2	1965-2006	36	0.387	34	0.05
VIIg	September	Raw mean length at age		3	1965-2006	36	0.387	34	0.05
VIIg	September	Raw mean weight at age		2	1975-2006	31	0.414	29	0.05
VIIg	September	Raw mean weight at age		3	1975-2006	31	0.363	29	0.05
VIIg	September	Fulton's condition factor		2	1972-2003	30	0.210	28	NS
VIIg	September	Fulton's condition factor		3	1971-2002	30	0.212	28	NS

Table 3.8.1 (c) Product Moment Correlation coefficients (r) and significance levels between *Calanus finmarchicus* abundance in VIIa and VIIg and various biological variables. Sample size (n) and degrees of freedom (df) indicated. Note year class shows correlations conducted for the birth year.

Environmental variable	Month	Biological variable		Ages	Years Range	n	Corr.	df	Sig
VIIa	May	Absolute Growth Rate in MW		2/5	1971-2000	24	0.360	22	NS
VIIa	May	Absolute Growth Rate in ML		2/5	1968-2000	25	0.292	23	NS
VIIa	May	Raw mean length at age	year class	2	1968-2003	28	0.377	26	0.05
VIIa	May	Raw mean length at age	year class	3	1968-2002	27	0.361	25	NS
VIIa	May	Raw mean weight at age	year class	2	1976-2003	23	0.436	21	0.05
VIIa	May	Raw mean weight at age	year class	3	1976-2002	22	0.501	20	0.05
VIIa	May	Raw mean length at age		2	1968-2006	31	0.376	29	0.05
VIIa	May	Raw mean length at age		3	1968-2006	31	0.361	29	0.05
VIIa	May	Raw mean weight at age		2	1976-2006	26	0.461	24	0.05
VIIa	May	Raw mean weight at age		3	1976-2006	26	0.455	24	0.05
VIIa	May	Fulton's condition factor		2	1972-2003	26	0.506	24	0.01
VIIa	May	Fulton's condition factor		3	1971-2002	26	0.528	24	0.01
VIIa	September	Absolute Growth Rate in MW		2/5	1971-2000	29	-0.069	27	NS
VIIa	September	Absolute Growth Rate in ML		2/5	1959-2000	31	-0.075	29	NS
VIIa	September	Raw mean length at age	year class	2	1967-2003	33	0.097	31	NS
VIIa	September	Raw mean length at age	year class	3	1967-2002	32	0.097	30	NS
VIIa	September	Raw mean weight at age	year class	2	1975-2003	28	0.177	26	NS
VIIa	September	Raw mean weight at age	year class	3	1975-2002	27	0.169	25	NS
VIIa	September	Raw mean length at age		2	1967-2006	36	0.193	34	NS
VIIa	September	Raw mean length at age		3	1967-2006	36	0.194	34	NS
VIIa	September	Raw mean weight at age		2	1975-2006	31	0.219	29	NS
VIIa	September	Raw mean weight at age		3	1975-2007	31	0.262	29	NS
VIIa	September	Fulton's condition factor		2	1972-2003	31	0.160	29	NS
VIIa	September	Fulton's condition factor		3	1971-2002	31	0.082	29	NS
VIIg	May	Absolute Growth Rate in MW		2/5	1971-2000	27	-0.074	25	NS
VIIg	May	Absolute Growth Rate in ML		2/5	1958-2000	38	0.272	36	NS
VIIg	May	Raw mean length at age	year class	2	1960-2003	39	-0.182	37	NS
VIIg	May	Raw mean length at age	year class	3	1960-2002	38	-0.253	36	NS
VIIg	May	Raw mean weight at age	year class	2	1975-2003	27	-0.075	25	NS
VIIg	May	Raw mean weight at age	year class	3	1975-2002	26	-0.167	24	NS
VIIg	May	Raw mean length at age		2	1960-2006	41	-0.254	39	NS
VIIg	May	Raw mean length at age		3	1960-2006	41	-0.195	39	NS
VIIg	May	Raw mean weight at age		2	1975-2006	29	-0.178	27	NS
VIIg	May	Raw mean weight at age		3	1975-2006	29	-0.079	27	NS
VIIg	May	Fulton's condition factor		2	1972-2003	29	-0.122	27	NS
VIIg	May	Fulton's condition factor		3	1971-2002	29	-0.210	27	NS
VIIg	September	Absolute Growth Rate in MW		2/5	1971-2000	28	-0.042	26	NS
VIIg	September	Absolute Growth Rate in ML		2/5	1959-2000	31	0.181	29	NS
VIIg	September	Raw mean length at age	year class	2	1965-2003	33	0.108	31	NS
VIIg	September	Raw mean length at age	year class	3	1965-2002	32	0.044	30	NS
VIIg	September	Raw mean weight at age	year class	2	1975-2006	28	0.258	26	NS
VIIg	September	Raw mean weight at age	year class	3	1975-2002	27	0.093	25	NS
VIIg	September	Raw mean length at age		2	1965-2006	36	0.289	34	NS
VIIg	September	Raw mean length at age		3	1965-2006	36	0.247	34	NS
VIIg	September	Raw mean weight at age		2	1975-2006	29	0.371	27	0.05
VIIg	September	Raw mean weight at age		3	1975-2006	29	0.320	27	NS
VIIg	September	Fulton's condition factor		2	1971-2002	30	0.166	28	NS
VIIg	September	Fulton's condition factor		3	1971-2002	30	0.015	28	NS

Table 3.8.1 (d) Product Moment Correlation coefficients (r) and significance levels between assessment data (Spawning Stock biomass (SSB), Fishing Mortality (F) and Recruitment) and various biological variables. Sample size (n) and degrees of freedom (df) indicated. Note year class shows correlations conducted for the birth year.

Assessment variable	Biological variable		Ages	Years Range	n	Corr.	df	Sig
SSB	Absolute Growth Rate in ML		2/5	1958-2000	43	0.178	41	NS
SSB	Absolute Growth Rate in MW		2/5	1969-2000	32	0.502	30	0.01
SSB	Raw mean length at age	year class	2	1960-2003	44	0.300	42	0.05
SSB	Raw mean length at age	year class	3	1960-2002	43	0.299	41	NS
SSB	Raw mean weight at age	year class	2	1975-2003	29	-0.249	27	NS
SSB	Raw mean weight at age	year class	3	1975-2002	28	-0.323	26	NS
SSB	Raw mean length at age		2	1960-2006	47	0.144	45	NS
SSB	Raw mean length at age		3	1960-2006	47	0.244	45	NS
SSB	Raw mean weight at age		2	1975-2006	32	-0.188	30	NS
SSB	Raw mean weight at age		3	1975-2006	32	-0.104	30	NS
SSB	Fulton's condition factor		2	1972-2003	32	0.110	30	NS
SSB	Fulton's condition factor		3	1971-2002	32	0.083	30	NS
F(2-5)	Absolute Growth Rate in ML		2/5	1958-2000	43	-0.476	41	0.01
F(2-5)	Absolute Growth Rate in MW		2/5	1969-2000	32	-0.217	30	NS
F(2-5)	Raw mean length at age	year class	2	1960-2003	44	-0.114	42	NS
F(2-5)	Raw mean length at age	year class	3	1960-2002	43	-0.219	41	NS
F(2-5)	Raw mean weight at age	year class	2	1975-2003	29	0.056	27	NS
F(2-5)	Raw mean weight at age	year class	3	1975-2002	28	0.033	26	NS
F(2-5)	Raw mean length at age		2	1960-2006	47	0.149	45	NS
F(2-5)	Raw mean length at age		3	1960-2006	47	0.150	45	NS
F(2-5)	Raw mean weight at age		2	1975-2006	32	0.299	30	NS
F(2-5)	Raw mean weight at age		3	1975-2006	32	0.353	30	0.05
F(2-5)	Fulton's condition factor		2	1972-2003	32	0.076	30	NS
F(2-5)	Fulton's condition factor		3	1971-2002	32	0.038	30	NS
Recruitment	Absolute Growth Rate in ML		2/5	1958-2000	43	-0.044	41	NS
Recruitment	Absolute Growth Rate in MW		2/5	1969-2000	32	-0.023	30	NS
Recruitment	Raw mean length at age	year class	2	1960-2003	44	-0.069	42	NS
Recruitment	Raw mean length at age	year class	3	1960-2002	43	-0.063	41	NS
Recruitment	Raw mean weight at age	year class	2	1975-2003	29	-0.230	27	NS
Recruitment	Raw mean weight at age	year class	3	1975-2002	28	-0.247	26	NS
Recruitment	Raw mean length at age		2	1960-2006	47	-0.149	45	NS
Recruitment	Raw mean length at age		3	1960-2006	47	-0.017	45	NS
Recruitment	Raw mean weight at age		2	1975-2006	32	-0.240	30	NS
Recruitment	Raw mean weight at age		3	1975-2006	32	-0.118	30	NS
Recruitment	Fulton's condition factor		2	1972-2003	32	-0.111	30	NS
Recruitment	Fulton's condition factor		3	1971-2002	32	-0.012	30	NS

Table 3.8.2 A summary of the biological and environmental variables from 1958 – 2007.

		Years			
	Winter Rings	**1958 - 1973**	**1974 - 1983**	**1984 - 1997**	**1998 - 2006**
SSB		59255 - 126470	27876 - 61992	53469 - 77382	22946 - 44244
Landings		10599 - 44389	9711 - 24981	18404 - 26779	6944 - 18485
F (2-5ringer)		0.1559 - 0.7155	0.3912 - 0.9398	0.377 - 1.0597	0.3306 - 0.8049
Recruitment		248000 - 1076200	131600 - 738020	191670 - 1049560	104100-476830
Mean length	2	24.73 - 27.39	26.11 - 27.86	24.67 - 26.33	23.44 - 25.00
Mean length	3	26.98 - 28.67	27.68 - 29.12	26.00 - 27.68	24.93 - 26.48
Absolute Growth Rate in Mean length	2/5	1.35 - 1.88	1.56 - 1.81	1.49 - 1.71	1.47 - 1.62
Mean weight	2		0.16 - 0.19	0.12 - 0.16	0.10 - 0.13
Mean weight	3		0.17 - 0.22	0.14 - 0.18	0.12 - 0.15
Absolute Growth Rate in Mean weight	2/5	0.71 - 0.82	0.71 - 0.74	0.71 - 0.73	0.72
Fultons condition factor	2	0.17 - 0.19	0.14 - 0.18	0.12 - 0.14	0.10 - 0.12
Fultons condition factor	3	0.19 - 0.22	0.17 - 0.22	0.14 - 0.17	0.12 - 0.14
Allometric condition factor	2	0.002 - 0.003	0.001 - 0.006	0.001 - 0.011	0.001 - 0.009
Allometric condition factor	3	0.001 - 0.003	0.001 - 0.006	0.001 - 0.011	0.001 - 0.009
NAO January		-2.67 to +1.37	-1.23 to +1.87	-2.06 to +2.77	+0.93 to +1.53
SST Irish Sea		14 - 15	14 - 15	14 - 16	15 - 16
SST Celtic Sea		16 - 17	15 - 17	15 - 17	17 - 18
Calanus helgolandicus VIIa May		0 - 17	0.1 - 2.5	0 - 5	0 - 5.5
Calanus helgolandicus VIIa September		3 - 35	0 - 8	0 - 24.3	0.1 - 8.8
Calanus helgolandicus VIIg May		0.8 - 113.5	0.7 - 45	2.1 - 138.3	0 - 123.9
Calanus helgolandicus VIIg September		1.8 - 53.1	2.4 - 80.2	4.2 - 27.5	1.5 - 46.3
Calanus finmarchicus VIIa May		0.5 - 6	0 - 1.4	0 - 0.1	0 - 0.5
Calanus finmarchicus VIIa September		0 - 1.1	0 - 1.2	0 - 4.4	0 - 0.2
Calanus finmarchicus VIIg May		0 - 50	0 - 12.1	0 - 22	0 - 43.1
Calanus finmarchicus VIIg September		0 - 0.4	0 - 5.4	0 - 2.6	0 - 1.5

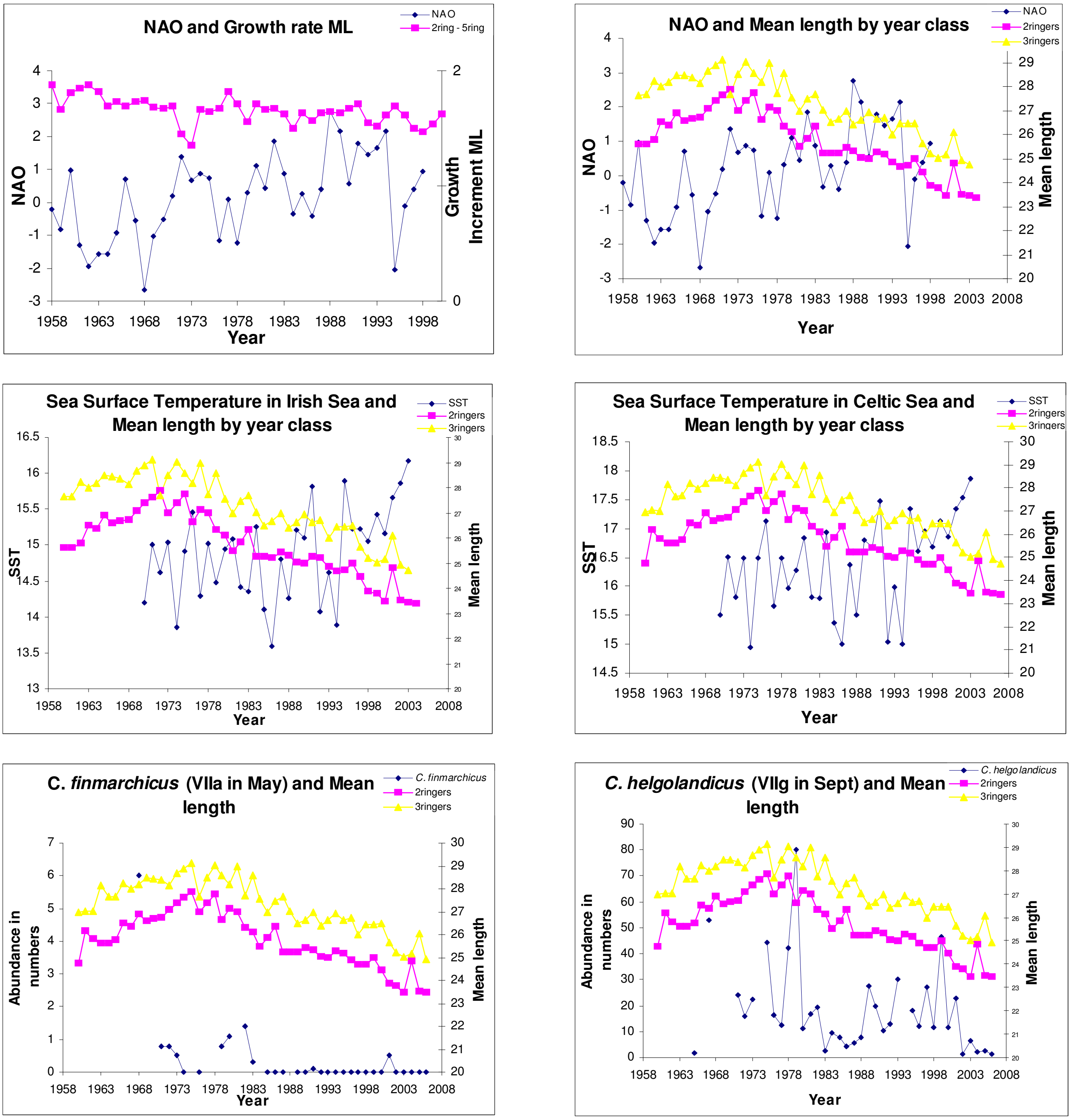


Figure 3.8.10 A range of the significant correlations found between the environmental and biological variables.

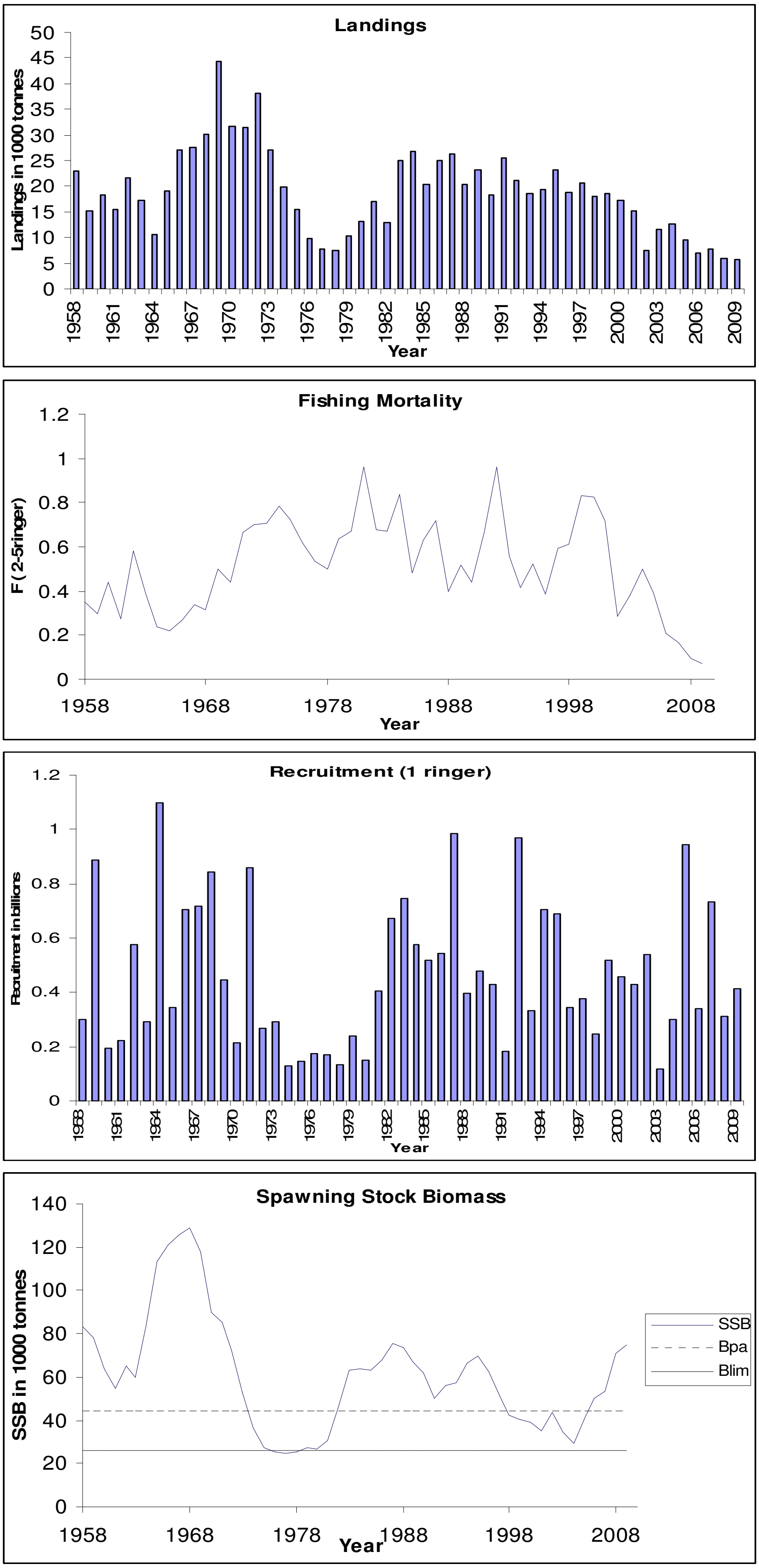


Figure 3.8.11. Periods in the recent history of the Celtic Sea and VIIj herring stock. Data from final assessment run performed by ICES HAWG in 2009 (Anon, 2009).

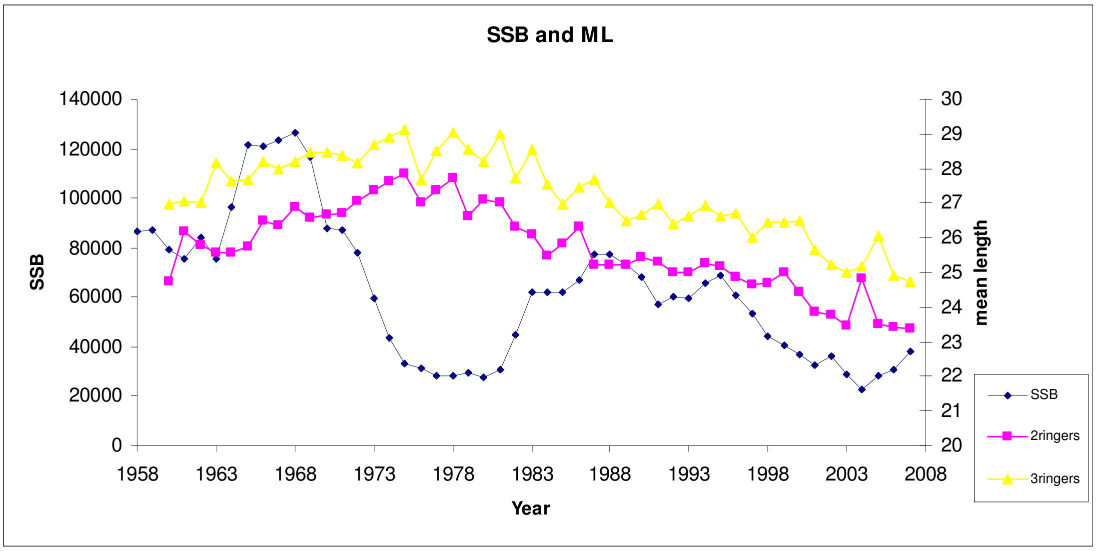


Figure 3.8.12 Spawning stock biomass (SSB) (tonnes) and Mean length (cm) in 2 and 3 ringers from 1958 – 2006.

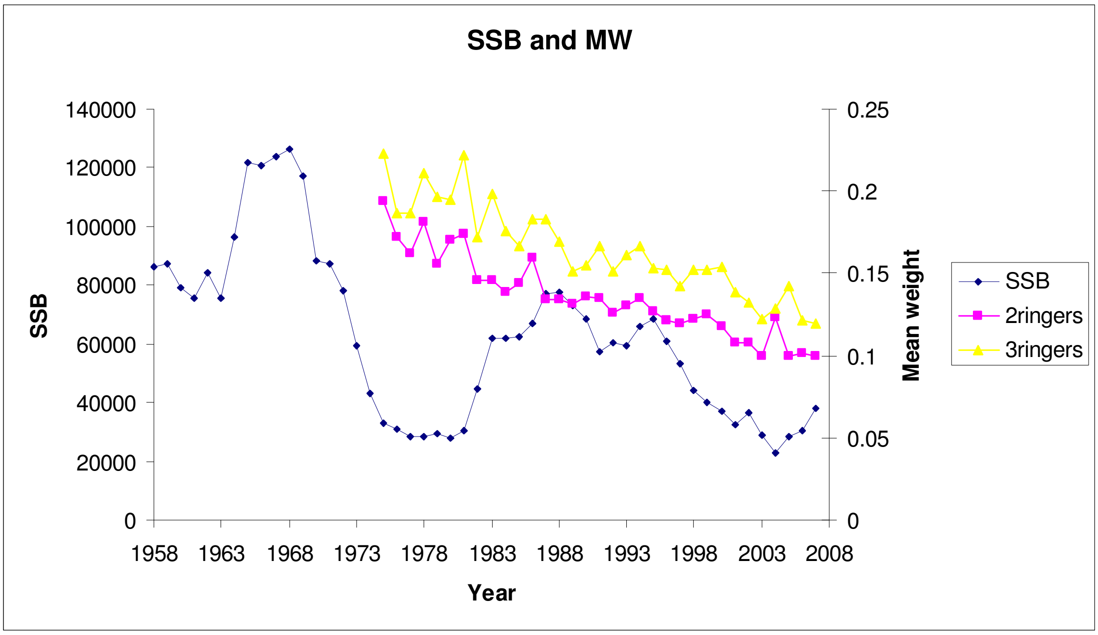


Figure 3.8.13 Spawning stock biomass (SSB) (tonnes) (1958 – 2006) and mean weight (kg) in 2 and 3 ringers (1975 – 2006).

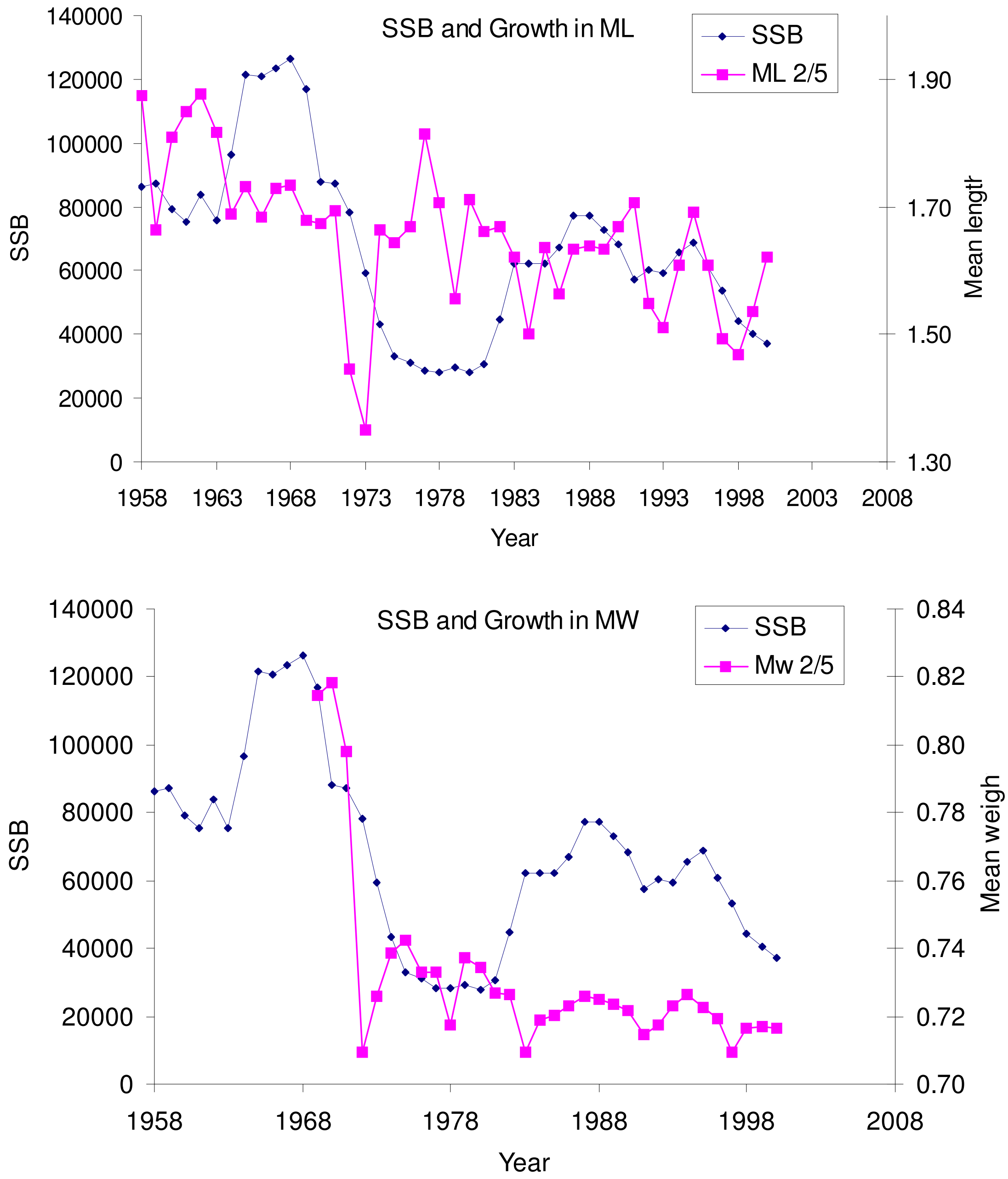
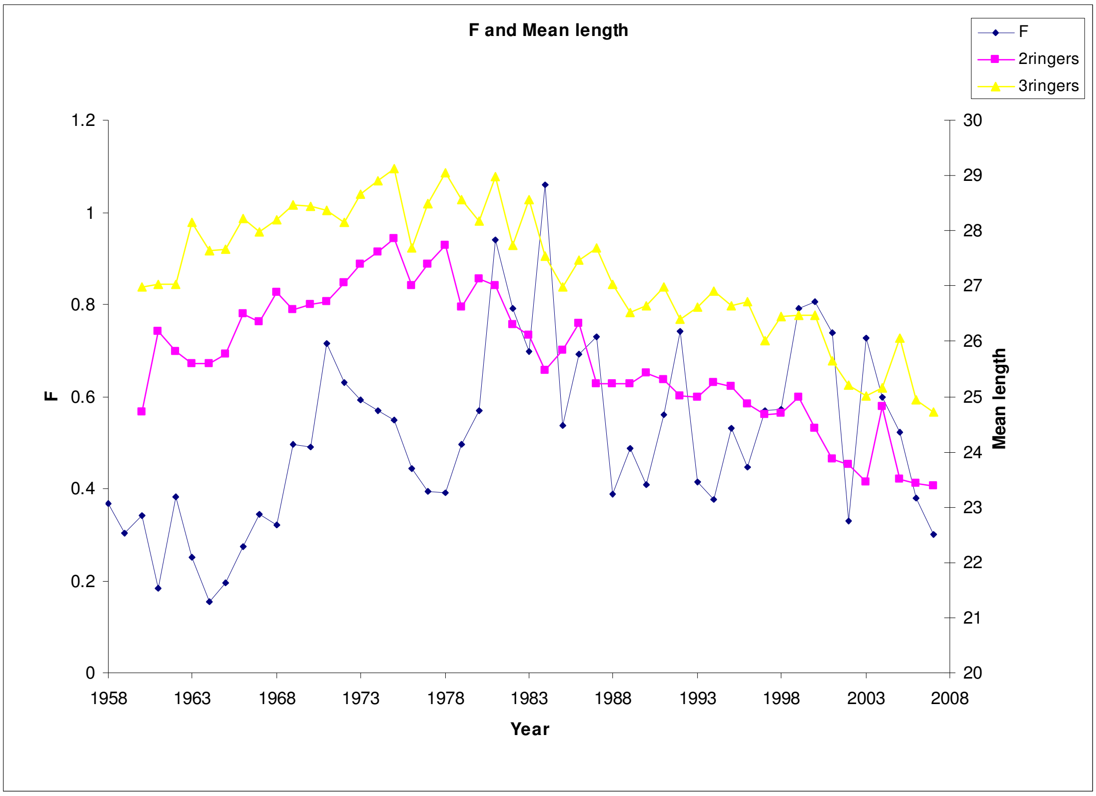


Figure 3.8.14 Comparison of absolute growth rate (cm) (2-5 winter rings) and Spawning stock biomass (SSB) (tonnes), for both mean length (cm) and mean weight (kg), over time series.



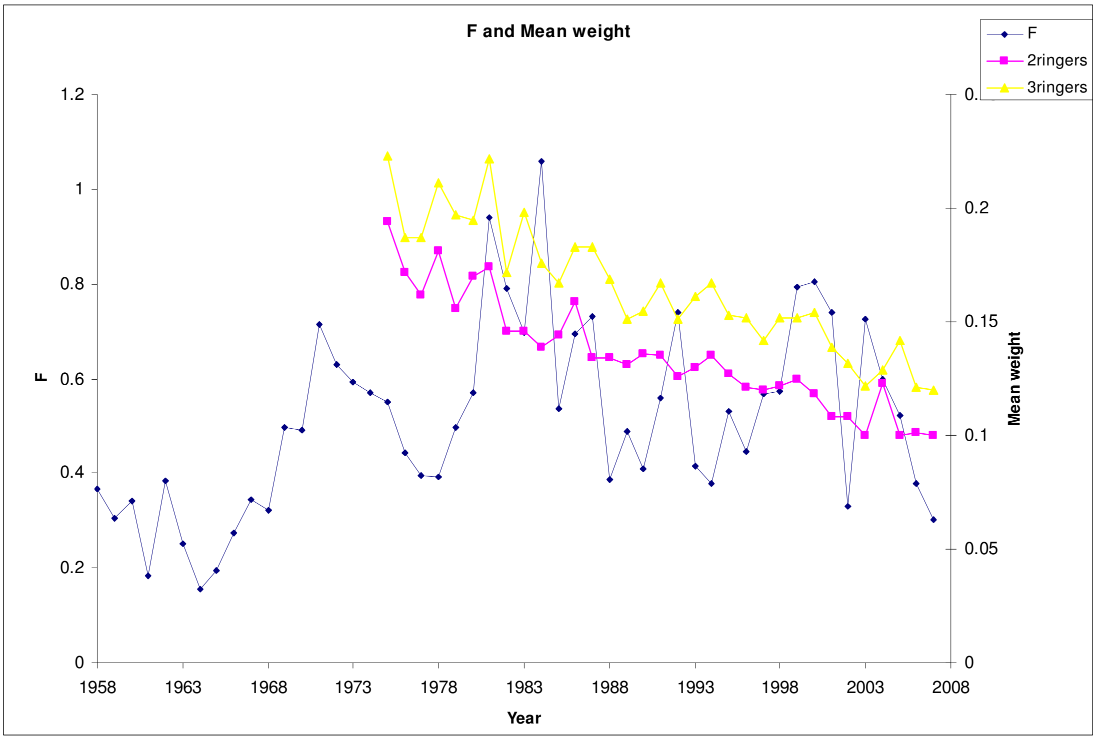
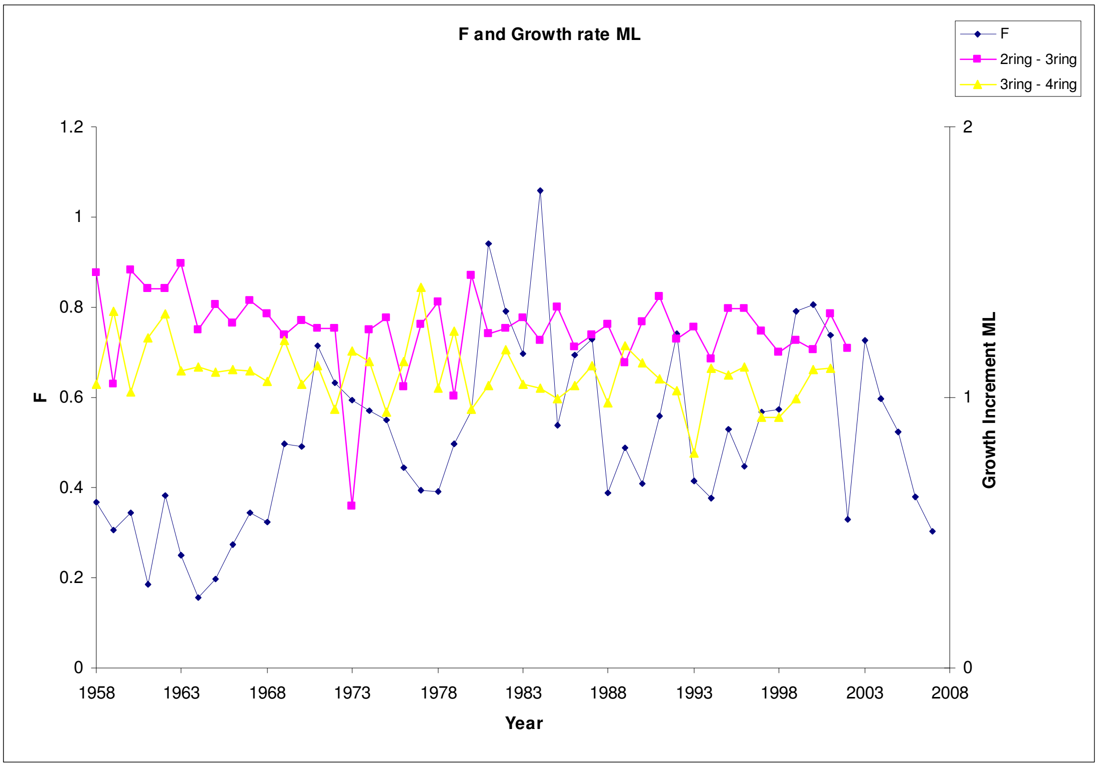


Figure 3.8.15 Fishing mortality (F –at-age) and mean length (cm) and mean weight (kg) for 2ringers and 3ringers.



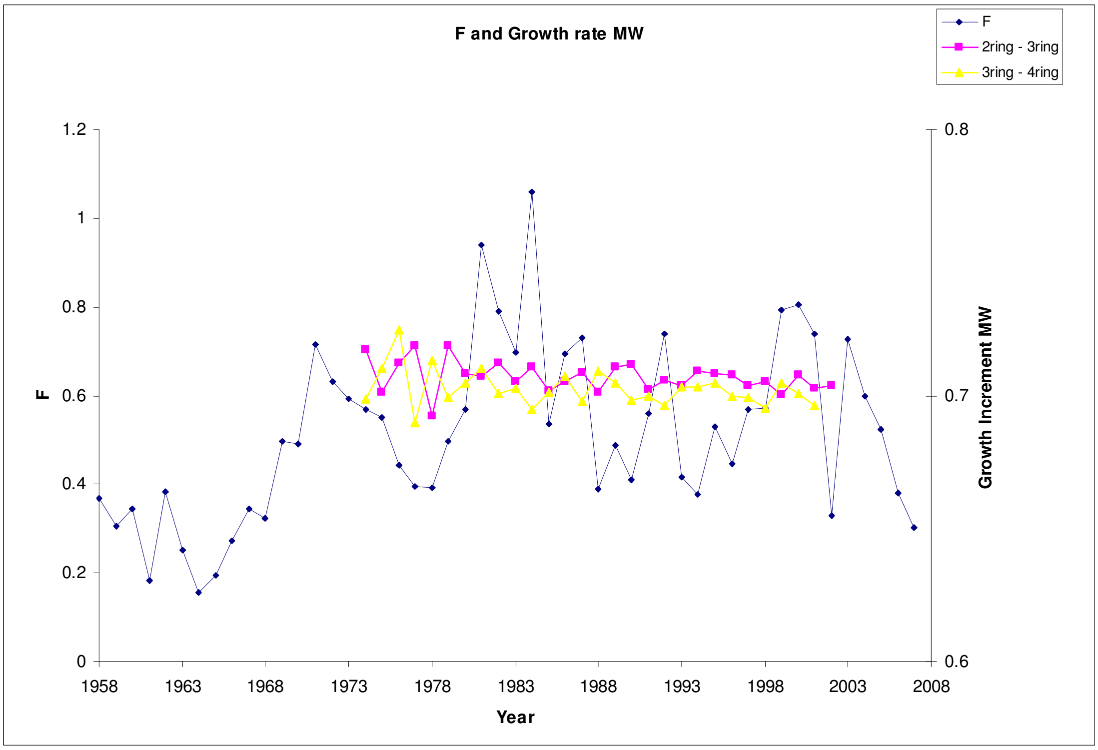
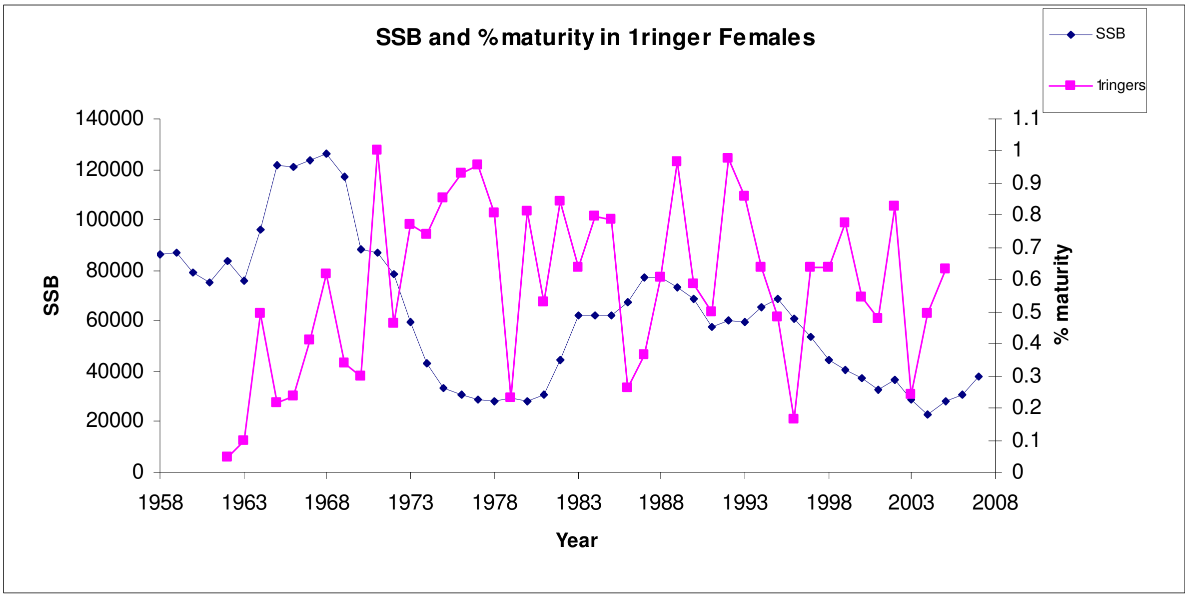


Figure 3.8.16 Fishing mortality (F at age) and growth increment in mean length (cm) and mean weight (kg).



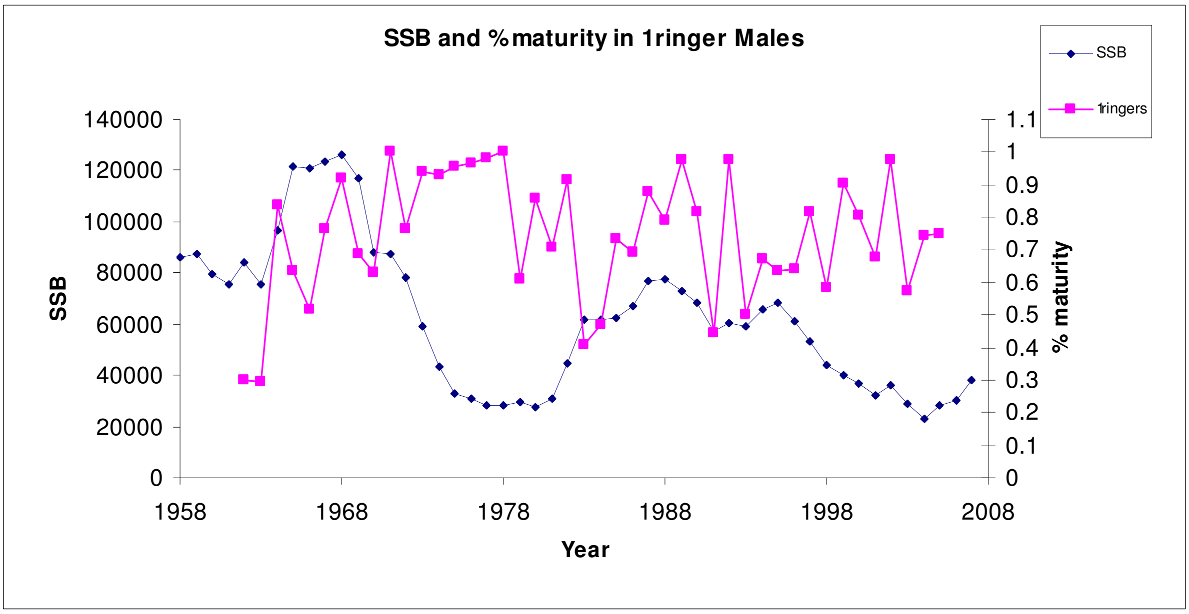
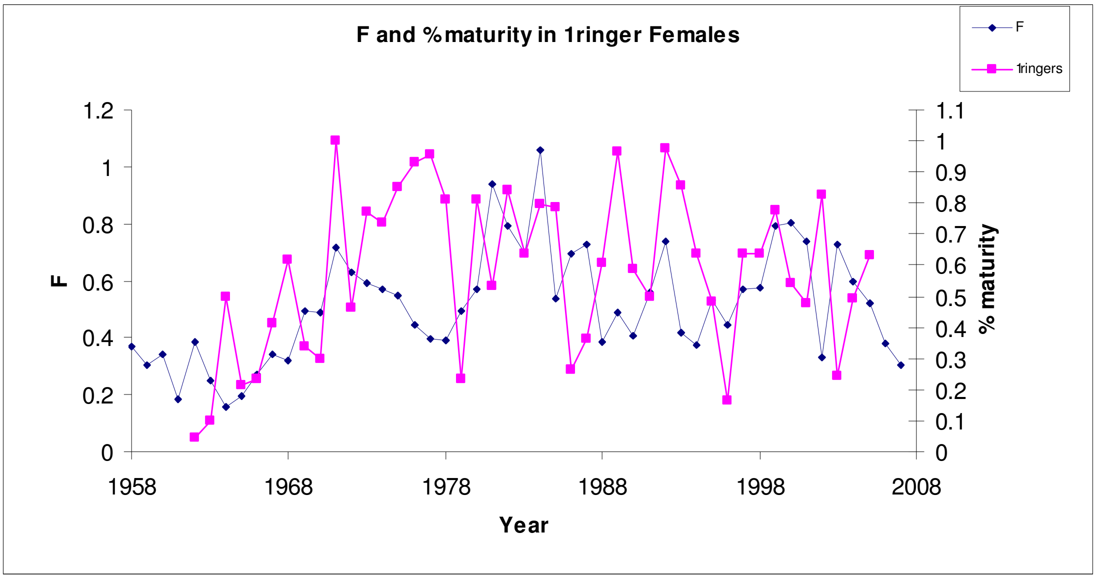


Figure 3.8.17 Spawning stock biomass (tonnes) and proportion mature in 1 ringer females and males



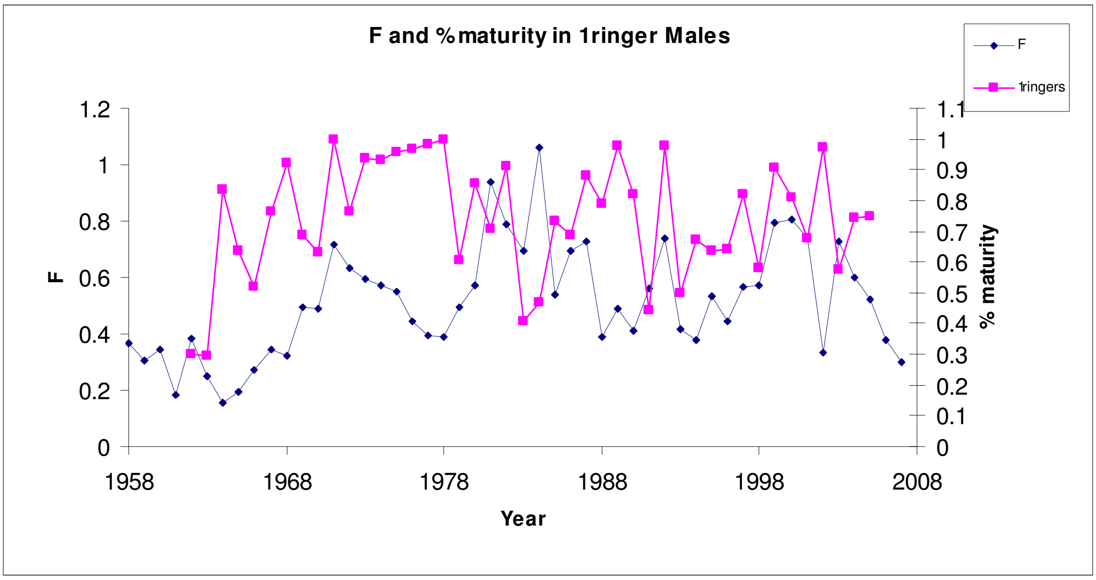
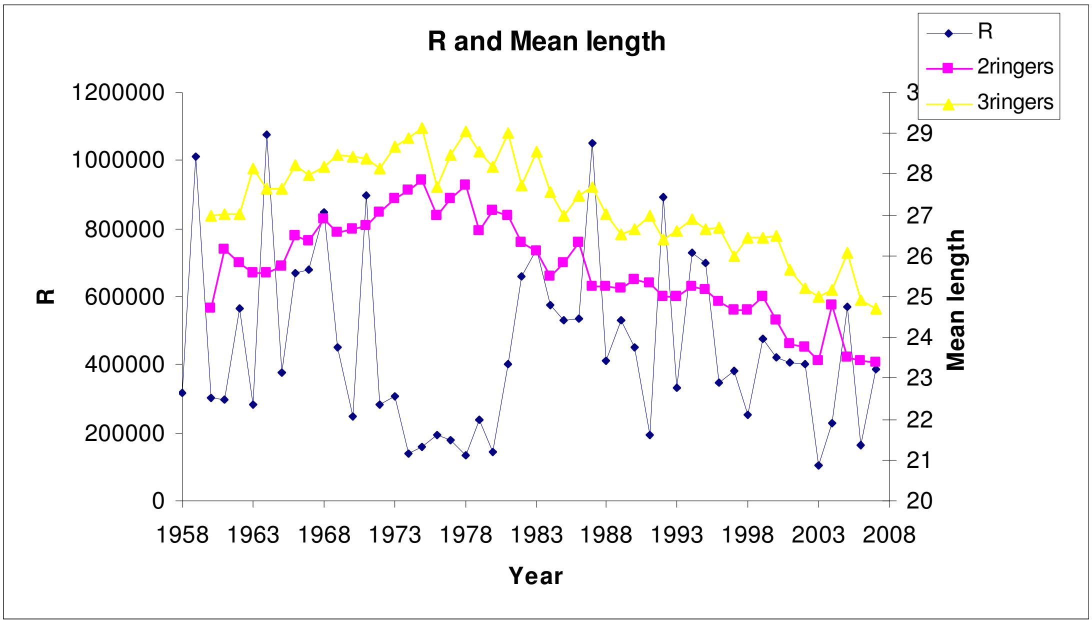


Figure 3.8.18 Fishing Mortality (F at age) and proportion mature in 1ringer females and males.



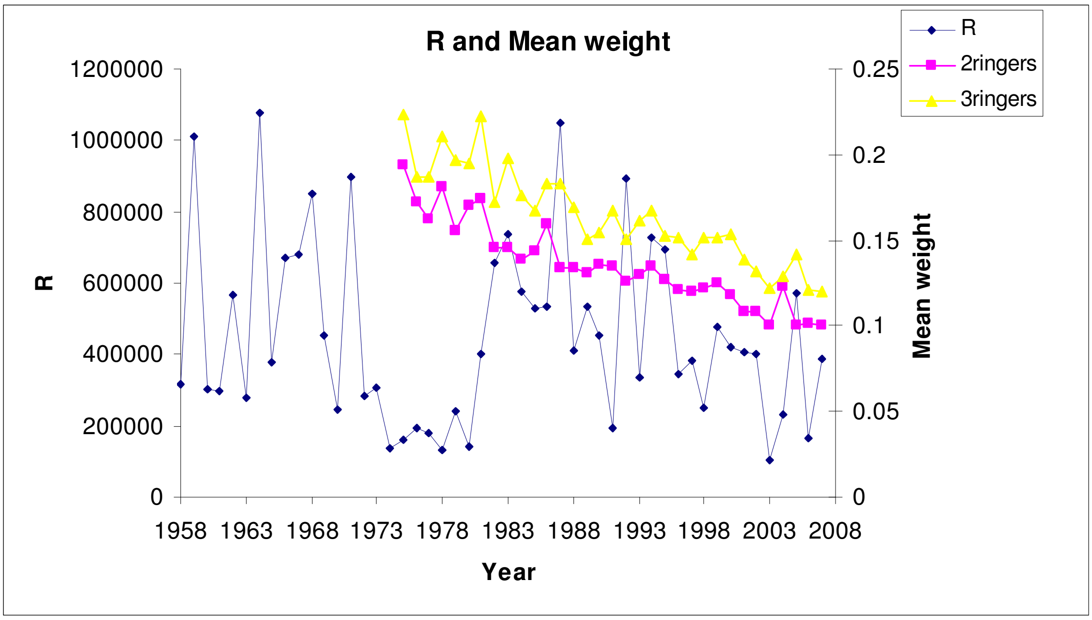
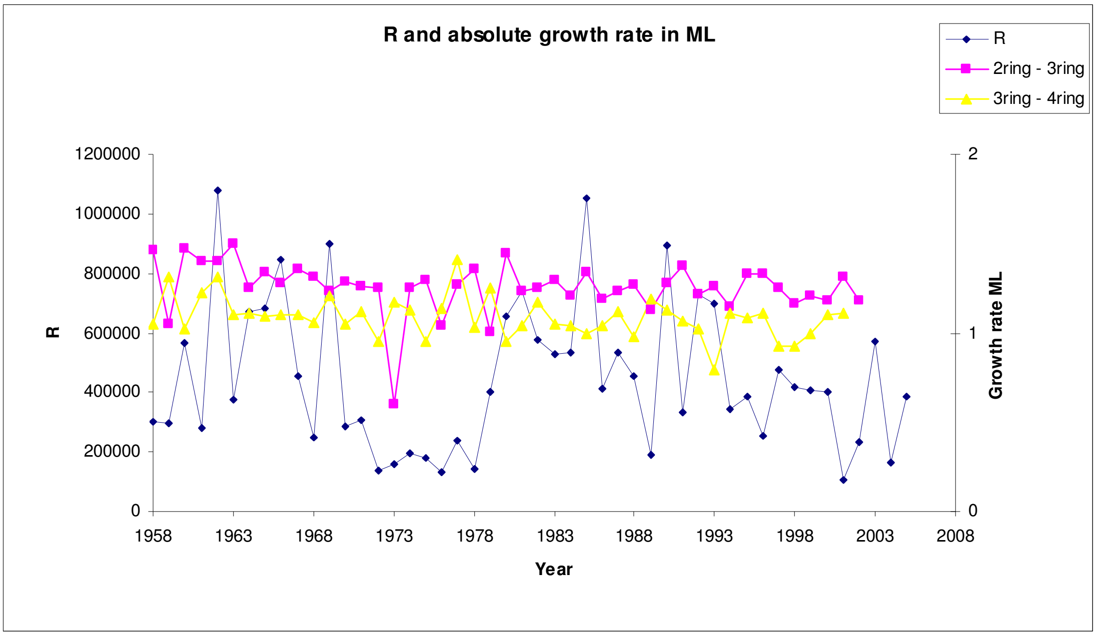


Figure 3.8.19 Recruitment (R) and mean length (cm) and mean weight (kg).



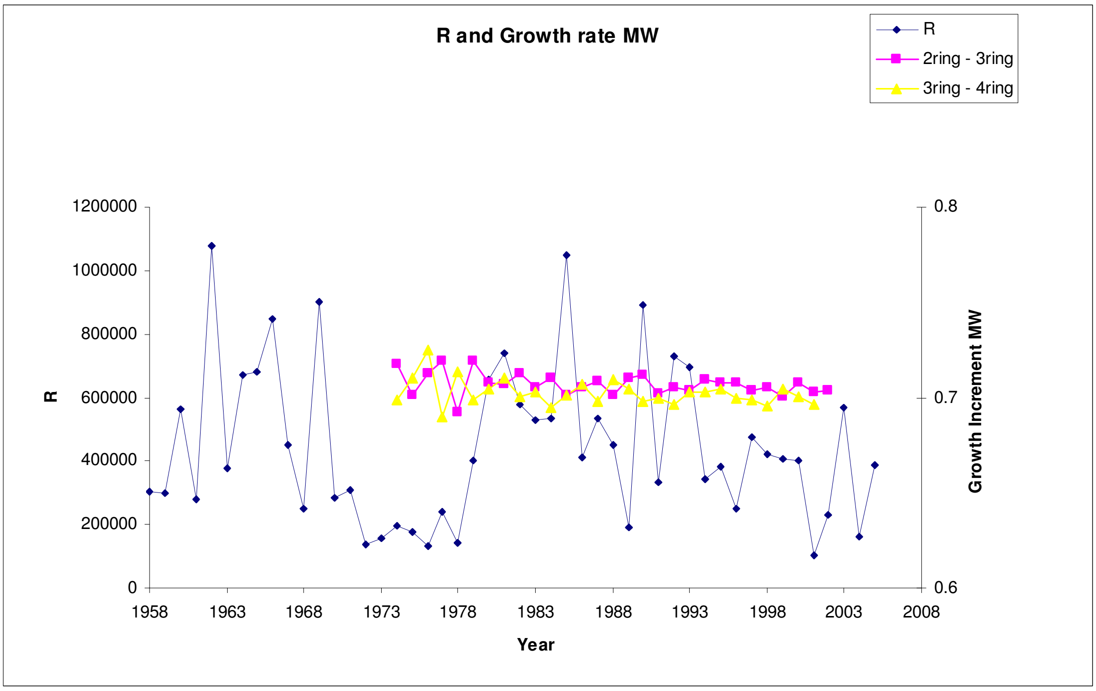


Figure 3.8.20 Recruitment (R) and growth rate in mean length (cm) and mean weight (kg)

4. DISCUSSION

4.1 Data collation and quality

Possible explanations for the trends shown in the biological data are discussed in Section 4.2. It is clear that these trends are not artefacts of sampling and the following information is presented to support this argument.

Throughout the series the same sampling and ageing protocols were adhered to and the number of samples collected (Tables 3.1.2 and 3.1.3) reflects the fishery. There were only 10 people involved in the sampling and 6 people involved in the ageing of Celtic Sea herring over the time series in this study. In each case, there was overlap between readers and samplers so that the expertise was transferred. One scientist (John Molloy) shared in the sampling and ageing work from 1964 to 2005. This ensured a high degree of consistency with other samplers and readers.

The age readers regularly performed comparison studies and an example of the kind of age comparison studies conducted is shown in Appendix V. This greatly reduces the element of error/drift and insures the consistency of the protocol. However, there has been no comparable study done on sampling. To date the sampling protocol was changed only once, in 2003 from random sampling to stratified sampling where 5 fish per length class was collected in each sample. It was however decided after 2003 to change the protocol back to random sampling in 2004.

The variance in the weight or length at age data was not calculated. This analysis would require the re-programming of the database, which was beyond the scope of the project, and time available. However, ICES examined the precision in the estimation of catch numbers at age for several countries' sampling programmes in 2006. This was done using a bootstrap technique that involves the re-sampling and processing of the measured and aged data. Irish sampling of the main age groups (2-4 winter rings) of Celtic Sea herring had CVs of between 5.32 and 11.38%. This is a high level of precision. The CV for 1-ring herring was higher (14.42 – 51.74%) reflecting the variability in the occurrence of 1 winter ring fish in catches and samples (Anon, 2007). Although this only indicates the precision in one fishing season (2006/2007), it does however give some indication that for the main age groups there is very good precision in terms of age estimation and sampling. Further work is required to investigate precision over time in the series. Comparison of bubble plots (Figures 3.3.1 to 3.3.4) shows that cohorts were well tracked in each area, and overall. This shows that the sampling programme for age was good at picking up strong cohorts in successive years.

The present study allowed for concerns about the quality of the data used in the stock assessment to be addressed. In 1982, the Celtic Sea stock (VIIaS, VIIg) was combined with the stock in VIIj for assessment and management purposes. The stock had been assessed separately up until then. Prior to 1984, the ICES Working Group used a constant set of data for mean weights at age. In 2000, mean weight at age for 1958-1983 was recalculated by applying a single length weight relationship to mean length at age data for those years (Kelly, 2000). Table 3.5.1 illustrates the co-efficient of determination (r^2) for the length weight relationship by year and indicates that the relationships fit the data well.

Table 3.5.2 which displays the slope and intercept of males and female separately for 10 years of data shows that there is little or no difference in the length and weight relationship between males and females in the dataset. No statistical comparison was made between sexes. This is because the purpose of this study was to examine trends in length, weight and condition at a population level. Since the stock is assessed at a population level, and not by sex, this seems appropriate.

Mean lengths for main age group (2-5ringers) in 2006 are between 11% and 16% lower than those in the peak year of 1975. The effect is more pronounced for mean weight for these main age groups with declines of between 40% and 47%. This is because weight is related to length by an approximately cubic relationship. The peaks in mean length and weight occurred earlier, for the younger ages. This can be seen for mean length in Figure 3.4.2 and for mean weight in Figure 3.4.4 which shows that there was a cohort effect. This cohort effect can also be seen in the absolute growth rates. These growth rates showed cohorts from the 1960s and 1970s tended to grow faster whilst those from the 1980s and 1990s were slower growing (Table 3.7.2 a and b)

The data presented in this study have some differences to those used in the stock assessment. The official landings figures were used to raise the stock assessment data but a full record of these catch weights by ICES Division and quarter was not available for this study. However, for the purposes of this analysis this is not important as shown in section 3.2. The mean length and mean weight at age remains the same whether actual landed weight or a nominal value of 1,000 t is used. The values are different because they are raised to the true landings but the proportions at age are the same as in the reconstructed data.

There are a few differences evident in comparisons between the dataset used by ICES, and the reconstructed dataset based on Irish sampling. The reason for this is that the assessment data includes Q3, Q4 and Q1 of the fishing season for each year and the reconstructed data are just Q4 and Q1 of the fishing season. However in comparison, the trends are the same showing an incline until the mid 1970s and declining trend there after. During Q3, herring are in better condition and are therefore heavier at any given age. The reconstructed data were based on Q4 and Q1 (autumn/winter) of the fishing season and this is a good indication of size/weight at age during spawning season.

An examination of the maturity by age for females and males show that there were two periods where the patterns are very different. They are presented in Table 3.6.1 and Figure 3.6.1 (b) for females (2 and 3 winter rings) and Table 3.6.2 and Figure 3.6.2 (b) for males (2 and 3 winter rings). In 1978 and 1979 full maturity was not attained until fish were 4 or 5 winter rings. The paper records were checked and the data were found to have been entered correctly. Therefore reasons for this outlier are unknown.

The 2003/2004 season appears as another outlier because fish did not attain full maturity until 6 or 7 winter rings. This is probably an artefact of a change in sampling in that year. This was the only season where non-random sampling was used for biological sampling of the catches and this season is excluded from further discussion about maturity patterns. Late maturity could have been observed because older fish had a higher chance of being sampled in a non random sampling scheme.

From Figure 4.1.1 it can be seen that the stocks around or near Ireland all have experienced a decline to below average mean weights in recent years. The Celtic Sea and Clyde stocks switched to below average mean weights in the early 1980s. In the Irish Sea the switch was in the late 1980s and in the west of Scotland, in the early 1990s. In contrast, the North Sea herring has not had a switch, but rather several fluctuating positive and negative periods, whilst the Norwegian spring spawning stock showed more marked fluctuations.

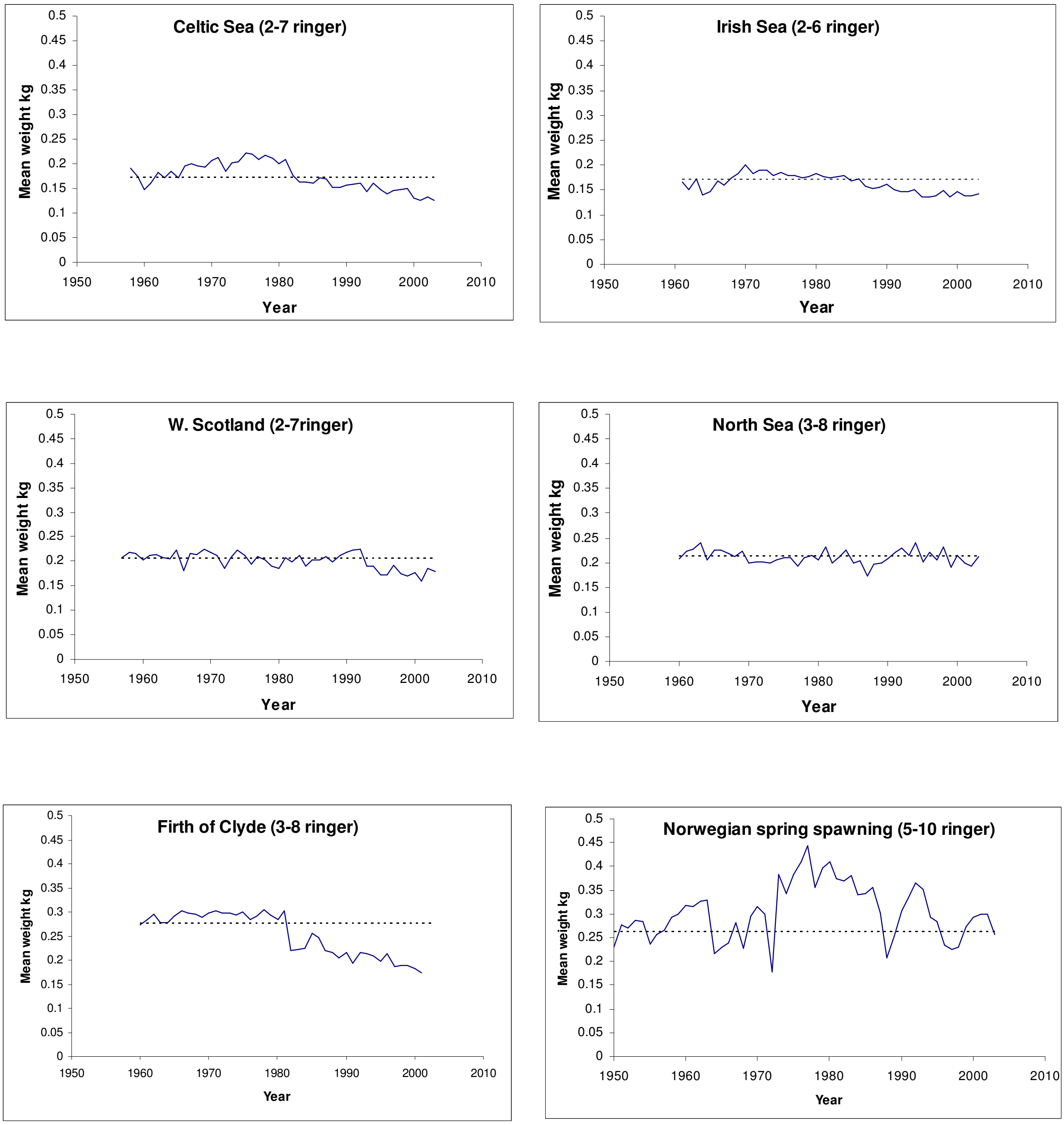


Figure 4.1.1. Comparison of mean weights at age for the several ICES herring stocks. Based on catch-number re-weighted data for main ages, from unpublished ICES data, 2004. The long term mean is indicated by dotted line in each graph.

4.1.1 <u>Environmental data collection and quality</u>

The sea surface temperature data used in this study were taken from the gridded sea surface temperature dataset HadSST2 which is from Hadley Centre for Climate Prediction and Research (Rayner *et al.*, 2005). Hughes *et al.* (2009) compared this dataset along with other gridded sea surface temperature datasets and *in situ* time series of temperature. The HadISST2 dataset was found to have a consistent correlation with the *in situ* data and was overall better than the other long-time data series (ERSST.v3). It was concluded from the study that SST gridded datasets can be useful indicators of long-term variability provided caution is used if studying the data in more detail (Hughes *et al*, 2009).

Sea surface temperature averages per year (Sept) from HadSST2 dataset for Celtic Sea and Irish Sea show slight variation from 1970 – 1984. The temperature becomes more variable after this and there is a strong increase from 1994 onwards. For historical comparison, the data were compared to earlier data presented by Farran (1939). Farran presented mean monthly temperatures in the south coast of Ireland from 1925 – 1937 and comparing the same month (September), the lowest temperature was in 1931 (13.66°C) and highest was in 1933 (15.56°C). This is lower than the data presented in this study for the modern period, which shows the lowest temperature in 1974 (14.94) and highest in 2003 (17.87).

The NAO winter index data used in this study were obtained from the Climate Research Unit and are available in the public domain. The NAO index is associated with the strength of westerly winds in Western Europe. During high NAO winters, the westerlies onto Europe are over 8 m/s stronger than during low NAO winters (Hurrell, 1995). The 3-year moving average used in the present study agrees with a model applied by Hurrell to the NAO winter index. It shows that from the mid 1950s to the mid 1970s the NAO was in a negative phase, and since has been mainly positive.

The abundance data for *Calanus finmarchicus* and *Calanus helgolandicus* is quite noisy with *Calanus finmarchicus* showing many zero values in all areas. This may not be due to variable effort, because it can be seen from Tables 2.10.1-2.10.3 and Figures 3.8.3 – 3.8.8 that there was reasonably consistent sampling in each month and in most years since the 1960s apart from VIIa which starts in the early 1970s.

In ICES Division VIIa both species of *Calanus* show a low abundance level (Figures 3.8.3 and 3.8.4) especially in the month of May. In ICES Division VIIg *Calanus finmarchicus* again shows quite low abundance in both months while *Calanus helgolandicus* shows much higher levels of abundance that VIIa especially in May (Figure 3.8.5 and 3.8.6). In ICES Division VIIj, *Calanus finmarchicus* is again quite low for both months while *Calanus helgolandicus* has high number for some years in May but quite low abundance in September with the exception of 1981 (Figures 3.8.7 and 3.8.8)

Calanus finmarchicus is a cold water species, and has undergone a northward shift over the last few decades (Beaugrand *et al*., 2002). The only high values for this species were for VIIg May in 1958 and in 2002 and some lower numbers in 1982, 1987 and 1991. The low, noisy data for this species in this study could be explained by the fact that it is not currently an important part of the zooplankton in the Celtic Sea, occurring in only 10% of samples (Johns, 2008). Overall trends are as reported for the whole Celtic Sea and English Channel area. Abundance was high in the late 1950s, declined to low levels in the 1960s and 1970s and increased in the 1980s, decreasing since (Johns, 2008).

It is clear from the CPR data that *C. helgolandicus* is more abundant than *C. finmarchicus.* This agrees with regional trends (Johns, 2008). *C. helgolandicus* appears to have increased in abundance since the 1980s, especially in VIIg. Though the data are noisy (Figures 3.8.3 to 3.8.8) they do agree with general trends presented by Johns (2008) and Planque and Fromentin (1996).

The CPR survey only provides information on the subsurface distribution of species. Therefore, changes in abundance presented in this study only refer to this zone (Johns, 2008). *Calanus* species undergo vertical migrations (Williams & Conway 1980, Hirche 1983, Williams 1985) and this means that the CPR may not give a good index of overall abundance of these species. Planque and Fromentin (1996) state that the abundance of *C. finmarchicus* is constant in surface waters throughout the year, but not for *C. helgolandicus*. This suggests that the data used in this project for the more abundant *C. helgolandicus* over time, may underestimate abundance.

4.2 Changes in growth and condition

From the data collated and analysed in this project it is clear that growth in herring off the south of Ireland had both low and a high phases in the past 50 years. Historical data (Burd and Bracken, 1965) suggest that in the 1920s and 1930s growth was intermediate.

Changes in growth over time have been reported by several authors (e.g. Bridger, 1961; Hubold, 1978; Cardinale and Arrhenius, 2000; Rahikainen and Stephenson, 2004; Casini *et al*, 2006; Oskarrson, 2008) mostly with reference to changes in mean length at age, mean weight at age or condition.

Increases in length at age and weight at age were reported for Downs herring for the period of 1933-1961 (Bridger, 1961). Baltic herring displayed an increase in mean length at age and mean weight at age from the 1970s to the mid 1980s and a decline thereafter (Rahikainen, and Stephenson, 2004). A similar trend was reported by Melvin and Stephenson (2007) for the Georges Bank Stock in the Northwest Atlantic. These authors noted that the length and weight at age were highest when the stock was in a state of collapse.

Different explanations have been put forward for changes in growth over time. Some authors cited density dependence alone. Other authors suggested environmental or trophic factors. More recently a combination of density dependence and other factors has been proposed.

Toresen (1990) showed that weak year classes displayed higher mean length at age than strong year classes in the Norwegian Sea. He suggests that density dependence could be responsible in some areas but changes also could be due to dispersion of young herring to areas with colder temperatures which would cause lower growth rates. Therefore slower growth was due to a combination of density dependence and associated environmental factors. Cardinale and Arrhenius (2000) suggest that the decline in weight at age and condition of herring in the Baltic Sea was due to increased competition with other pelagic fish for food.

Casini *et al* (2006) suggested that the decline in growth in the Baltic Sea in the 1990s was due to "food resources mediated density-dependant fish growth". In other words, the increased biomass of herring and other pelagic species created greater competition for the food source available. Hay *et al* (2001a) describe how the 1977 year class in NE Pacific was very strong. This may have been due to environmental factors which caused increased copepod abundance in the nurseries and therefore increased the availability of food.

Oskarrson (2008) could not find a relationship between condition factor of Icelandic herring and temperature and zooplankton abundance. However, he did find that high stock size is associated with lower condition in herring. Watanabe *et al*. (2008) stated that high temperatures during winter have a negative effect on the growth of Japanese herring and found weak indications of density dependant growth in the stock.

The present study looked for explanations for these trends. In the following paragraphs the various possible explanations are discussed.

Changing proportions of autumn and winter spawners

A possible explanation for the peak in length and weight at age in the 1970s is that there was a shift in the relative abundance of autumn and winter/spring spawning components. Autumn spawning herring tend to be larger (Molloy, 1968) in this area. By the late 1970s, in the Celtic Sea the autumn component was dominant (Molloy, 1979). However, earlier, in the late 1950s winter spawning herring were dominant (Bracken and Foster, 1963). At present the winter spawning component is dominant again (Molloy, 2006).

The results of Harma *et al.* (2009) suggest that each component was experiencing similar reductions in growth since the 1970s. They show that the overall decline in mean length and mean weight is not due to a change in the relative abundance of the two components

High fishing mortality

It is clear from Figure 3.8.11 that fishing mortality has been high and this has led to a stock collapse, when recruitment was low (1970s and early 2000s). However there is no obvious biological reason why a high fishing mortality (F) would lead to lower growth, especially at low stock size. There was high fishing mortality when growth was increasing in the early 1970s, and when growth was declining in the 1980s and 1990s. High fishing pressure can lead to the selective removal of fast growing fish and a reduction in length at age (Sinclair, et al, 2002)

Density dependence

Some scientistis have attributed changing growth to density dependence. Melvin and Stephenson (2007) working on George's Bank herring and Oskarrson (2008) on Icelandic summer spawners showed that when SSB was high, growth was low. On the other hand, Watanabe *et al*. (2008) reported that density dependence was not responsible for changing growth in Japanese herring. A few authors, such as Toresen (1990) and Cardinale and Arrhenius (2000) felt that density dependence, in conjunction with other factors was responsible for the growth changes they examined in Norwegian spring spawning and Baltic herring respectively.

In the present study, it is clear, from Figure 3.8.12-3.8.14 that changes in growth are not density-dependent. The two periods of high stock size in the past 50 years have seen both increasing and decreasing growth. The two low periods of stock size have seen high and low growth. This suggests that the changes in growth are not dependent on stock size (SSB). If decreasing growth is not density dependent, then perhaps it is driven by environmental factors, as Molloy (1984) speculated.

The Celtic Sea is very different from the Baltic Sea or Norwegian Sea, with many more dynamic links in its food web. This may explain why density dependent competition is not so important here. In other words, the Celtic Sea is a much more dynamic system, and more complicated than the Norwegian and Baltic Seas. Therefore even if competition was increasing between herring and other species it may be masked by other factors.

Environmental factors

The strongest influence on growth appears to be the NAO. The January NAO index showed a significant ($p<0.01$) negative correlation with growth rate in length. The growth rate in weight did not correlate well, maybe due to the shorter time series. However the length correlation shows that positive NAO is associated with lower growth rate in length over the 42-year period 1958 and 1999.

Increased temperature might be expected to influence growth either positively or negatively, depending on the geographic location of the stock. Hay *et al* (2001a) found that increased food abundance linked to increased temperature led to better growth of a particularly strong year class. In contrast Watanabe *et al* (2008) stated that high temperatures during winter had a negative effect on the growth of Japanese herring.

In this study, sea surface temperature in September had a weak negative correlation with mean length/weight and condition factor, more so in the Irish than in the Celtic Sea. There were fewer significant correlations between SST and growth/condition in the Celtic Sea. There is evidence that increased temperature is associated with reduced size/weight at age and condition, particularly in the Irish Sea. Temperature increases are most pronounced in mid 1990s and were variable up until this point. As the decline in growth and condition of Celtic sea herring began in the mid 1970s, it suggests that global warming is not strongly linked to this decline.

Calanus helgolandicus abundance was positively correlated with size and weight at age in the Celtic Sea (VIIg) whilst *Calanus finmarchicus* correlated positively in the Irish Sea (VIIa). Perhaps this is explained by the more northern distribution of the latter species. Also, in the Irish Sea, there was a highly significant positive correlation between *C. finmarchicus* and Fulton's condition factor. It is known that the nutritional value for development and growth of fish larvae is lower in *C. helgolandicus* than in *C. finmarchicus* (Anon, 2006). This may explain why higher abundance of the latter species is associated with better condition. Good abundance of *C. finmarchicus* at the larval stage probably leads to the fish having better condition as adults.

<u>Multiple interactions</u>

It should be noted that the effects of fishing, density and environment could act in combination and interact and the relative importance of each factor may not be constant across the time series. Therefore it is necessary to examine a combination of all the environmental and population variables together. Analysis of simultaneous effects is beyond the scope of the study. However the univariate correlations conducted are a necessary first step in implementing the ecosystem approach to fisheries management for this stock.

4.3 Maturity

In the present study, early maturity was observed when the stock was at both high and low stock size. Therefore it appears that early maturity is not just related to low stock size and is thus density independent. This was noted by Molloy (1979). The first early maturing year classes (Figure 3.8.17) were born when the SSB was already very low (Figure 3.8.17). This finding is in contrast to that of Engelhard and Heino (2004), who found that when SSB was low, Norwegian herring matured at an earlier age.

Toresen (1990) found that weaker year classes in Norwegian Spring Spawners had a stronger growth rate before maturity and weaker after maturity. However the Celtic Sea year classes were relatively fast growing at all ages. Perhaps this is because Celtic Sea herring do not live as long, but they continue to grow after maturity is reached. In contrast, for the long-lived Norwegian herring, the fish invest energy in growth first and in reproduction afterwards (Beverton, *et al*., 2004). The Celtic Sea herring appear to be at the other extreme, they mature early but continue to grow afterwards.

It is shown in Section 4.1.1 that there are two periods where maturity was not reached until advanced age (late 1970s and in 2003). In the latter case this may be explained by a change in sampling protocol. An additional factor may be due to the low stock size at both these periods (Figure 3.8.17). Brophy and Danilowicz (2002) showed that late maturing 1-ringers leave the Irish Sea and appear as 2-ringers in the Celtic Sea catches. New information (Beggs, 2008) indicates that some older fish also stay in the Irish Sea and return as 3- or even 4-ringers to the Celtic Sea. It is possible that when stock size was low, the relative proportion of late maturing fish from the Irish Sea was greater. This may explain why observed maturity in the catches was later in those years.

4.4 Conclusions

The current study examined changes in growth in this stock. It is clear that growth rates have reduced since the late 1950s in mean length and mid 1970s in mean weight. This change does not appear to be density dependent. Peak size/weight in the 1970s was associated with an increase in the autumn spawning component. However, there is some evidence that the autumn spawning component was experiencing a change in growth rate at that time. Considering each spawning component separately, or the stock as a whole, the explanations for changing growth seem to be environmentally driven.

The current study found evidence that declining growth was associated with a positive NAO since the late 1970s. There is also evidence that higher summer temperature has a negative effect on growth. It was more difficult to investigate the effect of *Calanus* abundance. However, there were some correlations that showed that higher copepod abundance had a positive influence on growth and condition.

This stock has always had early maturation (1-ringer onwards). It is clear that growth continues even after maturation. However a shift towards earlier maturation took place in the 1970s. This study shows this shift to early maturation has been sustained. It also shows that early maturation is not density dependent.

The biological changes have important implications for the management of this stock. The decline in mean weight at age results in more individual fish per tonne of landings. Hence a given quota consists of more fish, and exerts a greater fishing mortality than the same quota would have done, 25 years ago. The declines in size, weight and condition might also affect the profitability of the fishery. Most importantly, however, the target biomass level (B_{pa} = 44,000 t), contains a greater number of individuals and would be more difficult to reach, when the SSB is low.

4.5 Future work

The current study compiled all available biological information in the same format and presented the main trends over time. These data were compared with stock status data and show that the trends are not due to density dependence, or exploitation rate. As a next step towards explaining these trends, key environmental data were collated and correlated with the biological data. Further work on the environmental data should be investigated at a finer spatial scale. Further investigations could also focus on additional environmental factors such as the Atlantic Multi-Decadal Oscillation, sea roughness, wind direction and speed and the abundance of copepods other than *Calanus*. In particular links between environmental drivers and proportion of autumn and winter spawning components should also be investigated.

This study did highlight the need for minor re-working of some biological data. The 2003/2004 season data needs to be re-weighted to account for the fact that they were not collected randomly. Also, trends over time in maturity at length should be investigated. Statistical analysis of length, weight and condition by year and age is the subject of dedicated study, because this is a large task.

It would be useful to have updated fecundity estimates for this stock. Previous studies found similar estimates, but none have been conducted since the 1970s.

Finally, similar studies should be performed for the other herring stocks around Ireland. The same kind of biological data have been collected routinely for them also, and have been collected since the 1950s. Such historical analyses have been performed for Norwegian, Baltic and Canadian stocks. However no recent analysis of biological trends, as conducted by the present study, has been attempted for any other herring stocks around Ireland, Scotland or in the North Sea.

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Appendices

Appendix I Standard Sampling protocol and an example of raw data sheet used to record biological information

Sampling Protocol of Celtic Sea herring

- Collect a sample from each pair that lands, half – full fish box (depending on size range) is sufficient. If collecting from processor make sure sample is **ungraded and random.**
- Record info for sample – boat name, fishing area, date landed etc and if possible find out roughly how much the boat landed.
- Randomly take 75 fish for ageing. Record length in 0.5cm, weight, sex, maturity (use maturity scale for guideline). Extract otolith taking care not to break tip, store it in otolith tray clean and dry.
- Record a tally for the 75 aged fish under Aged Tally on datasheet.
- Measure the remaining fish and record a tally on the measured component of datasheet

HERRING AGED SHEET

SPECIES | SIZE CATEGORY | G / R | DIVISION | SAMPLING LOCATION

DATE | GEAR | COMMENTS | SAMP INIT

REC INIT

LANDED | GROUND | BOAT

			Aged Only Sample											
Length	Aged Tally	Measured component of aged sample	No	Length	Weight	Sex & Maturity		Age	No	Length	Weight	Sex & Maturity		Age
0			1						51					
0.5			2						52					
1			3						53					
1.5			4						54					
2			5						55					
2.5			6						56					
3			7						57					
3.5			8						58					
4			9						59					
4.5			10						60					
5			11						61					
5.5			12						62					
6			13						63					
6.5			14						64					
7			15						65					
7.5			16						66					
8			17						67					
8.5			18						68					
9			19						69					
9.5			20						70					
0			21						71					
0.5			22						72					
1			23						73					
1.5			24						74					
2			25						75					
2.5			26						76					
3			27						77					
3.5			28						78					
4			29						79					
4.5			30						80					
5			31						81					
5.5			32						82					
6			33						83					
6.5			34						84					
7			35						85					
7.5			36						86					
8			37						87					
8.5			38						88					
9			39						89					
9.5			40						90					
0			41						91					
0.5			42						92					
1			43						93					
1.5			44						94					
2			45						95					
2.5			46						96					
3			47						97					
3.5			48						98					
4			49						99					
4.5			50						100					

Appendix II Celtic Sea herring maturity scale (field guide used when sampling)

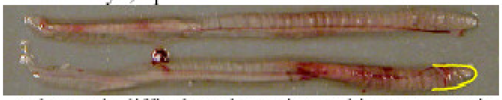
Marine Institute
Foras na Mara

Herring Maturity Scale

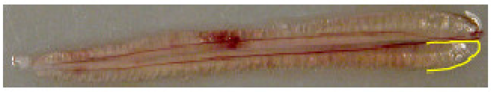
Females	Males

1. Juvenile

Ovaries very small, transparent, no eggs visible to naked eye, up to 3mm wide.



Testes very small, transparent up to 3mm wide.



The sex is difficult to determine at this stage: ovaries have a pointed end and are shaped like a torpedo and testes have a rounded end and are shaped like a scalpel

2. Developing virgin

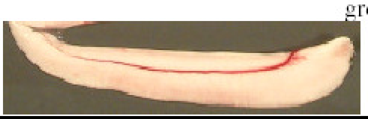
Ovaries somewhat larger in volume than stage I: 3-8mm wide. Eggs visible with magnifying glass. Still transparent.

Testes somewhat larger in volume than at stage I: 3-8mm wide. Still transparent

3. Ripening 1

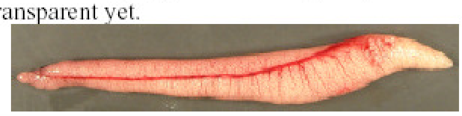
Ovaries more swollen and opaque, occupying about ½ of the ventral cavity. Yellow/white eggs in lamellae visible to naked eye.

Testes more swollen and opaque, occupying about ½ of the ventral cavity. Reddish grey or greyish.



4. Ripening 2

Ovaries pale yellow, filling about $^2/_3$ of the ventral cavity, eggs distinct and grainy not transparent yet.



Testes nearly filling $^2/_3$ of the ventral cavity, milt whitish.

5. Ripe

Ovaries filling ventral cavity. Some large transparent eggs present. Ovaries do not run under pressure

Testes filling ventral cavity, milt white, not yet running.

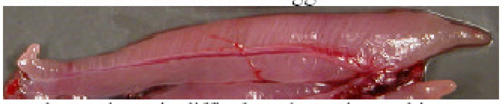
6. Running

Ovaries run when light pressure is applied, eggs transparent

Testes run when light pressure is applied

7. Recently spent

Ovaries slack with residual eggs

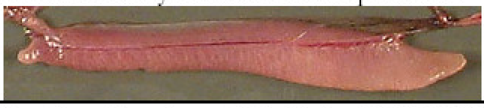


Testes baggy, bloodshot.

The sex is again difficult to determine at this stage, the shape of the gonads is more easily seen if they are spread out. Ovaries can be quite pointy while testes still have more or less scalpel shaped ends.

8. Spent-Recovering

Ovaries are firm and larger than stage 2. Walls striated vertically and blood vessels prominent

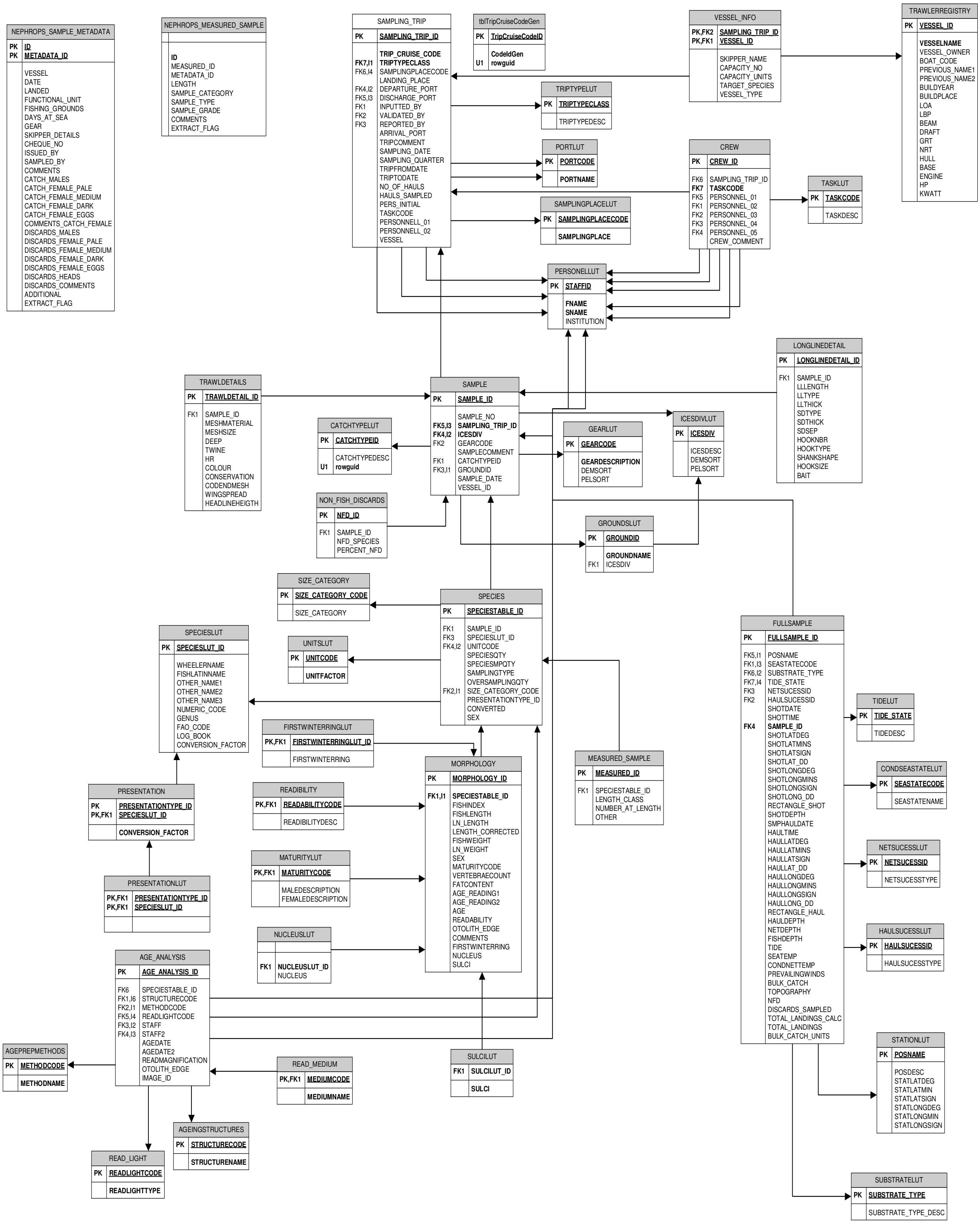


Testes are firm and larger than stage 2. Walls striated vertically and blood vessels prominent

Based on: (Landry and McQuinn 1988; ICES 2003)

Appendix III Stockman Database

Entity-relationship model showing a diagram of the tables in the database and the relationships between the tables. Fields are shown in tables.



Appendix III Stockman Database

Example of a stockman extraction

Fish Catch Summary						
Species - Herring		**Length Frequency Extraction Criteria**				
Landed Weight 192.802 Tonnes		**Ices Divisions**	**Gear**		**Date Boundary**	**Measured Samples**
		VIIg	Mid-Water Pair		Start Date - 01 October 2006	15463
			SingleMidwater		End Date - 31 December 2006	15677

Length Frequency

Length	Number
20	1
20.5	1
21	6
21.5	10
22	44
22.5	58
23	77
23.5	80
24	70
24.5	62
25	59
25.5	40
26	34
26.5	27
27	29
27.5	16
28	8
28.5	4
29	1
	627

Appendix III Stockman Database continued

Example of a stockman extraction

Length Weight Regression

This applies a modelled weight based on the length weight relationship to the corrected length (+0.25cm).

Sample No	Weight(g)	Age	Presentation	Length(cms)	Conversion	Corrected Length(cms)	Corrected Weight(g)	LnLength	LnWeight
15677	72	2	Round	21	1	21.25	72	3.06	4.28
15463	78	1	Round	21.5	1	21.75	78	3.08	4.36
15677	83	2	Round	21.5	1	21.75	83	3.08	4.42
15463	80	1	Round	22	1	22.25	80	3.1	4.38
15463	80	2	Round	22	1	22.25	80	3.1	4.38
15463	83	1	Round	22	1	22.25	83	3.1	4.42
15463	84	1	Round	22	1	22.25	84	3.1	4.43
15463	87	1	Round	22	1	22.25	87	3.1	4.47
15677	90	2	Round	22	1	22.25	90	3.1	4.5
15677	93	2	Round	22	1	22.25	93	3.1	4.53
15677	94	2	Round	22	1	22.25	94	3.1	4.54
15677	94	2	Round	22	1	22.25	94	3.1	4.54
15677	95	2	Round	22	1	22.25	95	3.1	4.55
15677	96	2	Round	22	1	22.25	96	3.1	4.56
15677	97	2	Round	22	1	22.25	97	3.1	4.57
15463	80	1	Round	22.5	1	22.75	80	3.12	4.38
15677	81	2	Round	22.5	1	22.75	81	3.12	4.39
15463	84	1	Round	22.5	1	22.75	84	3.12	4.43
15463	88	1	Round	22.5	1	22.75	88	3.12	4.48
15677	94	2	Round	22.5	1	22.75	94	3.12	4.54
15677	96	2	Round	22.5	1	22.75	96	3.12	4.56
15677	97	2	Round	22.5	1	22.75	97	3.12	4.57
15677	98	2	Round	22.5	1	22.75	98	3.12	4.58
15677	99	2	Round	22.5	1	22.75	99	3.12	4.6
15677	99	2	Round	22.5	1	22.75	99	3.12	4.6
15677	101	2	Round	22.5	1	22.75	101	3.12	4.62
15677	102	2	Round	22.5	1	22.75	102	3.12	4.62
15677	102	2	Round	22.5	1	22.75	102	3.12	4.62
15677	102	2	Round	22.5	1	22.75	102	3.12	4.62
15463	82	1	Round	23	1	23.25	82	3.15	4.41
15463	84	1	Round	23	1	23.25	84	3.15	4.43

Age Length Key (the red cells indicated "filled in" ages for lengths with no otoliths

This is used to allocate length at age to the total catch weight (see below)

	Age																															
Length	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
20		7																														7
20.5		11	1																													12
21			1																													1
21.5		1	1																													2
22		4	8																													12
22.5		3	11																													14
23		4	14																													18
23.5		4	13	6																												23
24		3	8	4																												15
24.5		1	7	5																												13
25			8	4																												12
25.5			3	6		1																										10
26			2	5	2																											9
26.5			1	2	2																											5
27				1	4	1																										6
27.5					2	2																										4
28				1	3		1																									5
28.5					1																											1
29								1																								1
29.5																																
																																170

Appendix III Stockman Database continued

Example of a stockman extraction

Length Weight Distribution

This raises the sampled weights per length to the total catch. A raising factor is used, this is: weight sampled/total catch weight

Length(cm)	Number Sampled	Mean Weight Observed(g)	Mean Weight Expected(g)	Weight Sampled(g)	Number Landed('000)	Weight Landed(Kg)
20	1	0	69	69	2.668	183.487
20.5	1	0	73	73	2.668	195.844
21	6	72	78	469	16.01	1252.259
21.5	10	80	83	832	26.683	2220.916
22	44	89	88	3892	117.407	10383.899
22.5	58	94	94	5444	154.763	14525.304
23	77	98	99	7659	205.462	20436.982
23.5	80	107	105	8423	213.467	22475.428
24	70	116	111	7792	186.783	20791.869
24.5	62	117	118	7288	165.437	19447.834
25	59	122	124	7316	157.432	19522.791
25.5	40	128	131	5227	106.733	13947.78
26	34	138	138	4677	90.723	12480.776
26.5	27	139	145	3906	72.045	10423.724
27	29	155	152	4409	77.382	11763.812
27.5	16	166	160	2553	42.693	6813.5
28	8	167	167	1339	21.347	3573.252
28.5	4	188	175	702	10.673	1872.378
29	1	0	184	184	2.668	490.165
29.5	0	0	192	0	0	0

Catch Numbers at Age

This applies length at age from ALK to the catch weight at length.

Note: SOP check is a comparison between the reported catch and the product of the catch numbers at age and mean weights at age

No/tonne whole wt landings	8677.524										
Landings whole weight(kg)	192802										
Landed Weight Tonnes	192.802										
SOP Check	100%										
Total No landed ('000s)	1673.044										
Summary	**Age0**	**Age1**	**Age2**	**Age3**	**Age4**	**Age5**	**Age6**	**Age7**	**Age8**	**Age9**	**Age10**
No landed ('000)	0	223.62	870.147	382.029	145.394	44.917	4.269	2.668	0	0	0
Mean Weight (kg)	0	0.099	0.107	0.125	0.153	0.151	0.167	0.184	0	0	0
% Distribution	0	13.37	52.01	22.83	8.69	2.68	0.26	0.16	0	0	0
Mean L (cm)	0	22.93	23.58	25	27.03	26.88	28	29	0	0	0
Mean L (+0.5 cm)	0	23.18	23.83	25.25	27.28	27.13	28.25	29.25	0	0	0
Length	**Age0**	**Age1**	**Age2**	**Age3**	**Age4**	**Age5**	**Age6**	**Age7**	**Age8**	**Age9**	**Age10**
20	0	2.668	0	0	0	0	0	0	0	0	0
20.5	0	2.446	0.222	0	0	0	0	0	0	0	0
21	0	0	16.01	0	0	0	0	0	0	0	0
21.5	0	13.342	13.342	0	0	0	0	0	0	0	0
22	0	39.136	78.271	0	0	0	0	0	0	0	0
22.5	0	33.164	121.6	0	0	0	0	0	0	0	0
23	0	45.658	159.804	0	0	0	0	0	0	0	0
23.5	0	37.125	120.655	55.687	0	0	0	0	0	0	0
24	0	37.357	99.618	49.809	0	0	0	0	0	0	0
24.5	0	12.726	89.081	63.63	0	0	0	0	0	0	0
25	0	0	104.955	52.477	0	0	0	0	0	0	0
25.5	0	0	32.02	64.04	0	10.673	0	0	0	0	0
26	0	0	20.161	50.402	20.161	0	0	0	0	0	0
26.5	0	0	14.409	28.818	28.818	0	0	0	0	0	0
27	0	0	0	12.897	51.588	12.897	0	0	0	0	0
27.5	0	0	0	0	21.346	21.346	0	0	0	0	0
28	0	0	0	4.269	12.808	0	4.269	0	0	0	0
28.5	0	0	0	0	10.673	0	0	0	0	0	0
29	0	0	0	0	0	0	0	2.668	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0

Appendix IV Terminology for herring ages (from Anon, 2003)

The ICES Herring Assessment Working Group uses “rings” rather than “age” or “winter rings” throughout its reports to denominate the age of herring, with the intention to avoid confusion. It should be observed that, for autumn spawning stocks, there is a difference of one year between “age” and “rings”. HAWG in 1992 (Anon 1992/Assess:11) stated that

“The convention of defining herring age rings instead of years was introduced in various ICES working groups around 1970. The main argument to do so was the uncertainty about the racial identity of the herring in some areas. A herring with one winter ring is classified as 2-years-old if it is an autumn spawner, and one-year-old if it is a spring spawner. Recording the age of the herring in rings instead of in years allowed scientists to postpone the decision on year of birth until a later date when they might have obtained more information on the racial identity of the herring.

The use of winter rings in ICES working groups has introduced a certain amount of confusion and errors. In specifying the age of the herring, people always have to state explicitly whether they are talking about rings or years, and whether the herring are autumn- or spring spawners. These details tend to get lost in working group reports, which can make these reports confusion for outsiders, and even for herring experts themselves. As the age of all other fish species (and of herring in other parts of the world) is expressed in years, one could question the justification of treating West-European herring in a special way. Especially with the present trend towards multispecies assessment and integration of ICES working groups, there might be a case for a uniform system of age definition throughout all ICES working groups.

However, the change from rings to years would create a number of practical problems. Data files in national laboratories and at ICES would have to be adapted, which would involve extra costs and manpower. People that had not been aware of the change might be confused when comparing new data with data from old working group reports. Finally, in some areas (notably Division IIIa), the distinction between spring- and autumn spawners is still hard to make, and scientists preferred to continue using rings instead of years.

The Working Group discussed at length the various consequences of a change from rings to years. The majority of the Group felt that the advantages of such a change did not outweigh the disadvantages, and it was decided to stick to the present system for the time being.”

The text table below gives an example for the correlation between age, rings and year class for the different spawning types in late 2002:

YEAR CLASS (AUTUMN SPAWNERS)	2001/2002	2000/2001	1999/2000	1998/1999
Rings	**0**	**1**	**2**	**3**
Age (autumn spawners)	**1**	**2**	**3**	**4**
Year class (spring spawners)	**2002**	**2001**	**2000**	**1999**
Rings	**0**	**1**	**2**	**3**
Age (spring spawners)	**0**	**1**	**2**	**3**

Appendix V Example of an age comparison study conducted in 2003 using Guus Eltinks from Netherlands Institute for Fisheries Research (RIVO) Age reading Comparison spreadsheet.

Table 1 Herring Otolith SET sample 4984,4986 2003

RANGE r. 1-15

	Sample		Fish	Fish		Landing	Deirdre	John M	Jan B	Eugene		**MODAL**	**Percent**	**Precision**
Stratum	year	no	no	length	Sex	month	Reader 1	Reader 2	Reader 3	Reader 4	Reader 15	**age**	**agreement**	**CV**
	2003	4984	1	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	2	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	3	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	4	27	-	7	3	4	4	4	-	**4**	75%	13%
-	2003	4984	5	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4984	6	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4984	7	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	8	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	9	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	10	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	11	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	12	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	13	27	-	7	2	2	3	3	-	**2**	50%	23%
-	2003	4984	14	27	-	7	4	5	4	5	-	**4**	50%	13%
-	2003	4984	15	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	16	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	17	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	18	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	19	27	-	7	3	2	2	2	-	**2**	75%	22%
-	2003	4984	20	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	21	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4984	22	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	23	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	24	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	25	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	26	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	27	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	28	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4984	29	27	-	7	2	3	3	3	-	**3**	75%	18%
-	2003	4984	30	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4984	31	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	32	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	33	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	34	27	-	7	3	4	4	4	-	**4**	75%	13%
-	2003	4984	35	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	36	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	37	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	38	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	39	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	40	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	41	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	42	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	43	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	44	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	45	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4984	46	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	47	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	48	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	49	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	50	27	-	7	5	4	5	5	-	**5**	75%	11%
-	2003	4984	51	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4984	52	27	-	7	1	1	1	1	-	**1**	100%	0%
-	2003	4984	53	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	54	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	55	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4984	56	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	57	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4984	58	27	-	7	3	2	2	2	-	**2**	75%	22%
-	2003	4984	59	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	60	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4984	61	27	-	7	5	6	6	6	-	**6**	75%	9%
-	2003	4984	62	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4986	1	27	-	7	10	10	11	11	-	**10**	50%	5%
-	2003	4986	2	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	3	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	4	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	5	27	-	7	6	6	6	6	-	**6**	100%	0%
-	2003	4986	6	27	-	7	7	7	7	7	-	**7**	100%	0%
-	2003	4986	7	27	-	7	7	7	8	8	-	**7**	50%	8%
-	2003	4986	8	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	9	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	10	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	11	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	12	27	-	7	6	6	6	6	-	**6**	100%	0%
-	2003	4986	13	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	14	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	15	27	-	7	9	9	10	10	-	**9**	50%	6%
-	2003	4986	16	27	-	7	7	7	7	7	-	**7**	100%	0%
-	2003	4986	17	27	-	7	8	8	9	9	-	**8**	50%	7%
-	2003	4986	18	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	19	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	20	27	-	7	6	6	6	6	-	**6**	100%	0%
-	2003	4986	21	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	22	27	-	7	4	5	5	5	-	**5**	75%	11%
-	2003	4986	23	27	-	7	7	7	7	7	-	**7**	100%	0%
-	2003	4986	24	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	25	27	-	7	6	6	6	6	-	**6**	100%	0%
-	2003	4986	26	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	27	27	-	7	6	7	6	6	-	**6**	75%	8%
-	2003	4986	28	27	-	7	8	8	8	8	-	**8**	100%	0%
-	2003	4986	29	27	-	7	7	9	8	8	-	**8**	50%	10%
-	2003	4986	30	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	31	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	32	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	33	27	-	7	9	9	9	9	-	**9**	100%	0%
-	2003	4986	34	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	35	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	36	27	-	7	10	10	10	10	-	**10**	100%	0%
-	2003	4986	37	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	38	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	39	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	40	27	-	7	6	6	6	6	-	**6**	100%	0%
-	2003	4986	41	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	42	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	43	27	-	7	2	2	2	2	-	**2**	100%	0%
-	2003	4986	44	27	-	7	7	7	7	7	-	**7**	100%	0%
-	2003	4986	45	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	46	27	-	7	6	6	6	6	-	**6**	100%	0%
-	2003	4986	47	27	-	7	4	4	4	4	-	**4**	100%	0%
-	2003	4986	48	27	-	7	3	3	3	3	-	**3**	100%	0%
-	2003	4986	49	27	-	7	5	5	5	5	-	**5**	100%	0%
-	2003	4986	50	27	-	7	9	9	9	9	-	**9**	100%	0%
-	-	-	-	-	-	-	-	-	-	-	-			
-	-	-	-	-	-	-	-	-	-	-	-			
						Total read	112	112	112	112	0		**94.9%**	**1.8%**
						Total NOT read	0	0	0	0	112			

Table 2 The number of age readings, the coefficient of variation (CV), the percent agreement and the RELATIVE bias are presented by MODAL age for each age reader and for all readers combined. A weighted mean CV and a weighted mean percent agreement are given by reader and all readers combined. The CV's by MODAL age for each individual age reader and all readers combined indicate the precision in age reading by MODAL age. The weighted mean CV's over all MODAL age groups comined indicate the precision in age reading by reader and for all age readers combined.

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NUMBER OF AGE READINGS

	MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	TOTAL
	0	-	-	-	-	-	-
	1	1	1	1	1	-	4
	2	28	28	28	28	-	112
	3	28	28	28	28	-	112
	4	22	22	22	22	-	88
	5	12	12	12	12	-	48
	6	8	8	8	8	-	32
	7	5	5	5	5	-	20
	8	3	3	3	3	-	12
	9	3	3	3	3	-	12
	10	2	2	2	2	-	8
	11	-	-	-	-	-	-
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
Total	0-15	112	112	112	112	0	448

COEFFICIENT OF VARIATION (CV)

	MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL Readers
	0	-	-	-	-	-	-
	1	-	-	-	-	-	-
	2	13%	0%	9%	9%	-	2.4%
	3	6%	0%	0%	0%	-	0.6%
	4	8%	5%	0%	5%	-	1.8%
	5	6%	6%	0%	0%	-	1.8%
	6	6%	6%	0%	0%	-	2.1%
	7	0%	0%	6%	6%	-	1.5%
	8	8%	7%	7%	7%	-	5.7%
	9	0%	0%	6%	6%	-	2.0%
	10	0%	0%	7%	7%	-	2.7%
	11	-	-	-	-	-	-
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
Weighted mean	0-15	7.5%	2.3%	3.1%	4.1%		1.8%
	RANKING	4	1	2	3		

PERCENTAGE AGREEMENT

	MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL
	0	-	-	-	-	-	-
	1	100%	100%	100%	100%	-	100%
	2	93%	100%	96%	96%	-	96%
	3	96%	100%	100%	100%	-	99%
	4	91%	95%	100%	95%	-	95%
	5	92%	92%	100%	100%	-	96%
	6	88%	88%	100%	100%	-	94%
	7	100%	100%	80%	80%	-	90%
	8	67%	67%	67%	67%	-	67%
	9	100%	100%	67%	67%	-	83%
	10	100%	100%	50%	50%	-	75%
	11	-	-	-	-	-	-
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
Weighted mean	0-15	92.9%	96.4%	95.5%	94.6%		94.9%
	RANKING	4	1	2	3		

RELATIVE BIAS

	MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL
	0	-	-	-	-	-	-
	1	0.00	0.00	0.00	0.00	-	0.00
	2	0.07	0.00	0.04	0.04	-	0.04
	3	-0.04	0.00	0.00	0.00	-	-0.01
	4	-0.09	0.05	0.00	0.05	-	0.00
	5	-0.08	-0.08	0.00	0.00	-	-0.04
	6	-0.13	0.13	0.00	0.00	-	0.00
	7	0.00	0.00	0.20	0.20	-	0.10
	8	-0.33	0.33	0.33	0.33	-	0.17
	9	0.00	0.00	0.33	0.33	-	0.17
	10	0.00	0.00	0.50	0.50	-	0.25
	11	-	-	-	-	-	-
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
Weighted mean	0-15	-0.04	0.02	0.04	0.05		0.02
	RANKING	2	1	3	4		

Overall ranking

	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15
Ranking Coefficient of Variation	4	1	2	3	
Ranking Percentage Agreement	4	1	2	3	
Ranking Relative bias	2	1	3	4	
OVERALL RANKING	3	1	2	3	

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Table 3 Upper table: The age compositions estimated by each age reader and all age readers combined.
Midle table: The estimated mean length at age by age reader and by all age readers combined.
Lower table: Bias tests: non-parametrically with a one-sample Wilcoxon rank sum test.The inter-reader bias test and the reader against MODAL age bias test.

AGE COMPOSITION

	Age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	TOTAL
	0	-	-	-	-	-	-
	1	1	1	1	1	-	4
	2	27	28	27	27	-	109
	3	31	28	29	29	-	117
	4	21	22	22	21	-	86
	5	12	12	12	13	-	49
	6	7	7	8	8	-	30
	7	6	6	4	4	-	20
	8	2	2	3	3	-	10
	9	3	4	3	3	-	13
	10	2	2	2	2	-	8
	11	-	-	1	1	-	2
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	-	-	-	-	-	-
	17	-	-	-	-	-	-
	18	-	-	-	-	-	-
	19	-	-	-	-	-	-
	20	-	-	-	-	-	-
Total	0-15	112	112	112	112	0	448

MEAN LENGTH AT AGE

	Age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL
	0	-	-	-	-	-	-
	1	27.0	27.0	27.0	27.0	-	27.0
	2	27.0	27.0	27.0	27.0	-	27.0
	3	27.0	27.0	27.0	27.0	-	27.0
	4	27.0	27.0	27.0	27.0	-	27.0
	5	27.0	27.0	27.0	27.0	-	27.0
	6	27.0	27.0	27.0	27.0	-	27.0
	7	27.0	27.0	27.0	27.0	-	27.0
	8	27.0	27.0	27.0	27.0	-	27.0
	9	27.0	27.0	27.0	27.0	-	27.0
	10	27.0	27.0	27.0	27.0	-	27.0
	11	-	-	27.0	27.0	-	27.0
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	-	-	-	-	-	-
	17	-	-	-	-	-	-
	18	-	-	-	-	-	-
	19	-	-	-	-	-	-
	20	-	-	-	-	-	-
Weighted mean	0-15	27.0	27.0	27.0	27.0	-	27.0

Inter-reader bias test and reader against MODAL age bias test

	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15
Reader 1					
Reader 2					
Reader 3					
Reader 4					
#REF!					
#REF!					
#REF!					
#REF!					
#REF!					
#REF!					
#REF!					
#REF!					
#REF!					
#REF!					
Reader 15					
MODAL age					

–	= no sign of bias (p>0.05)
*	= possibility of bias (0.01<p<0.05)
* *	= certainty of bias (p<0.01)

Herring Otolith SET sample 4984,4986 2003

Table 4 Otoliths read, CV's, percentage agreement and RELATIVE bias by month and by MODAL age.

NUMBER OF OTOLITHS

MODAL age	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	Nr of otoliths
0	-	-	-	-	-	-	-	-	-	-	-	-	0
1	-	-	-	-	-	-	1	-	-	-	-	-	1
2	-	-	-	-	-	-	28	-	-	-	-	-	28
3	-	-	-	-	-	-	28	-	-	-	-	-	28
4	-	-	-	-	-	-	22	-	-	-	-	-	22
5	-	-	-	-	-	-	12	-	-	-	-	-	12
6	-	-	-	-	-	-	8	-	-	-	-	-	8
7	-	-	-	-	-	-	5	-	-	-	-	-	5
8	-	-	-	-	-	-	3	-	-	-	-	-	3
9	-	-	-	-	-	-	3	-	-	-	-	-	3
10	-	-	-	-	-	-	2	-	-	-	-	-	2
11	-	-	-	-	-	-	-	-	-	-	-	-	0
12	-	-	-	-	-	-	-	-	-	-	-	-	0
13	-	-	-	-	-	-	-	-	-	-	-	-	0
14	-	-	-	-	-	-	-	-	-	-	-	-	0
15	-	-	-	-	-	-	-	-	-	-	-	-	0
TOTAL	0	0	0	0	0	0	112	0	0	0	0	0	112

COEFFICIENT OF VARIATION (CV)

MODAL age	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	Mean CV
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	0%	-	-	-	-	-	-
2	-	-	-	-	-	-	2%	-	-	-	-	-	2.4%
3	-	-	-	-	-	-	1%	-	-	-	-	-	0.6%
4	-	-	-	-	-	-	2%	-	-	-	-	-	1.8%
5	-	-	-	-	-	-	2%	-	-	-	-	-	1.8%
6	-	-	-	-	-	-	2%	-	-	-	-	-	2.1%
7	-	-	-	-	-	-	2%	-	-	-	-	-	1.5%
8	-	-	-	-	-	-	6%	-	-	-	-	-	5.7%
9	-	-	-	-	-	-	2%	-	-	-	-	-	2.0%
10	-	-	-	-	-	-	3%	-	-	-	-	-	2.7%
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean CV Weighted	-	-	-	-	-	-	1.8%	-	-	-	-	-	1.8%

Note: Higher CV's might be expected during months of opaque material deposition and during the juvenile phase, when false rings might occur!

PERCENTAGE AGREEMENT

MODAL age	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	Agree-ment
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	100%	-	-	-	-	-	100.0%
2	-	-	-	-	-	-	96%	-	-	-	-	-	96.4%
3	-	-	-	-	-	-	99%	-	-	-	-	-	99.1%
4	-	-	-	-	-	-	95%	-	-	-	-	-	95.5%
5	-	-	-	-	-	-	96%	-	-	-	-	-	95.8%
6	-	-	-	-	-	-	94%	-	-	-	-	-	93.8%
7	-	-	-	-	-	-	90%	-	-	-	-	-	90.0%
8	-	-	-	-	-	-	67%	-	-	-	-	-	66.7%
9	-	-	-	-	-	-	83%	-	-	-	-	-	83.3%
10	-	-	-	-	-	-	75%	-	-	-	-	-	75.0%
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean CV Weighted	-	-	-	-	-	-	94.9%	-	-	-	-	-	94.9%

RELATIVE BIAS

MODAL age	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	Mean bias
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	0.00	-	-	-	-	-	0.00
2	-	-	-	-	-	-	0.04	-	-	-	-	-	0.04
3	-	-	-	-	-	-	-0.01	-	-	-	-	-	-0.01
4	-	-	-	-	-	-	0.00	-	-	-	-	-	0.00
5	-	-	-	-	-	-	-0.04	-	-	-	-	-	-0.04
6	-	-	-	-	-	-	0.00	-	-	-	-	-	0.00
7	-	-	-	-	-	-	0.10	-	-	-	-	-	0.10
8	-	-	-	-	-	-	0.17	-	-	-	-	-	0.17
9	-	-	-	-	-	-	0.17	-	-	-	-	-	0.17
10	-	-	-	-	-	-	0.25	-	-	-	-	-	0.25
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	0.02	-	-	-	-	-	0.02

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Table 5 Otoliths read, CV's, percentage agreement and RELATIVE bias by stratum and MODAL age.

NUMBER OF OTOLITHS													
MODAL	SAMPLING STRATA												Nr of
age	Males	Females	C	D	E	F	G	H	I	J	K	L	otoliths
0	-	-	-	-	-	-	-	-	-	-	-	-	0
1	-	-	-	-	-	-	-	-	-	-	-	-	0
2	-	-	-	-	-	-	-	-	-	-	-	-	0
3	-	-	-	-	-	-	-	-	-	-	-	-	0
4	-	-	-	-	-	-	-	-	-	-	-	-	0
5	-	-	-	-	-	-	-	-	-	-	-	-	0
6	-	-	-	-	-	-	-	-	-	-	-	-	0
7	-	-	-	-	-	-	-	-	-	-	-	-	0
8	-	-	-	-	-	-	-	-	-	-	-	-	0
9	-	-	-	-	-	-	-	-	-	-	-	-	0
10	-	-	-	-	-	-	-	-	-	-	-	-	0
11	-	-	-	-	-	-	-	-	-	-	-	-	0
12	-	-	-	-	-	-	-	-	-	-	-	-	0
13	-	-	-	-	-	-	-	-	-	-	-	-	0
14	-	-	-	-	-	-	-	-	-	-	-	-	0
15	-	-	-	-	-	-	-	-	-	-	-	-	0
TOTAL	0	0	0	0	0	0	0	0	0	0	0	0	0

COEFFICIENT OF VARIATION (CV)													
MODAL	SAMPLING STRATA												Mean
age	Males	Females	C	D	E	F	G	H	I	J	K	L	CV
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean CV	-	-	-	-	-	-	-	-	-	-	-	-	-
Weighted													

PERCENTAGE AGREEMENT													
MODAL	SAMPLING STRATA												Agree-
age	Males	Females	C	D	E	F	G	H	I	J	K	L	ment
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean CV	-	-	-	-	-	-	-	-	-	-	-	-	-
Weighted													

RELATIVE BIAS													
MODAL	SAMPLING STRATA												Mean
age	Males	Females	C	D	E	F	G	H	I	J	K	L	bias
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	-	-	-	-	-	-
Weighted													

Table 6 TABLES FOR PLOTTING THE AGE BIAS PLOT FIGURES OF FIGURE 1

Herring Otolith SET sample 4984,4986 2003

2STDEV

MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	2STDEV ALL
0	-	-	-	-	-	-
1	-	-	-	-	-	0.000
2	0.525	0.000	0.378	0.378	-	0.373
3	0.378	0.000	0.000	0.000	-	0.189
4	0.588	0.426	0.000	0.426	-	0.429
5	0.577	0.577	0.000	0.000	-	0.404
6	0.707	0.707	0.000	0.000	-	0.508
7	0.000	0.000	0.894	0.894	-	0.616
8	1.155	1.155	1.155	1.155	-	1.155
9	0.000	0.000	1.155	1.155	-	0.778
10	0.000	0.000	1.414	1.414	-	0.926
11	-	-	-	-	-	-
12	-	-	-	-	-	-
13	-	-	-	-	-	-
14	-	-	-	-	-	-
15	-	-	-	-	-	-

MEAN AGE

	MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL
	0	-	-	-	-	-	-
	1	1.00	1.00	1.00	1.00	-	1.00
	2	2.07	2.00	2.04	2.04	-	2.04
	3	2.96	3.00	3.00	3.00	-	2.99
	4	3.91	4.05	4.00	4.05	-	4.00
	5	4.92	4.92	5.00	5.00	-	4.96
	6	5.88	6.13	6.00	6.00	-	6.00
	7	7.00	7.00	7.20	7.20	-	7.10
	8	7.67	8.33	8.33	8.33	-	8.17
	9	9.00	9.00	9.33	9.33	-	9.17
	10	10.00	10.00	10.50	10.50	-	10.25
	11	-	-	-	-	-	-
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
Weighted mean	**0-15**	**3.92**	**3.97**	**4.00**	**4.01**	**-**	**3.98**

MEAN AGE +2STDEV

MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL
0	-	-	-	-	-	-
1	-	-	-	-	-	1.00
2	2.596	2.000	2.414	2.414	-	2.41
3	3.342	3.000	3.000	3.000	-	3.18
4	4.498	4.472	4.000	4.472	-	4.43
5	5.494	5.494	5.000	5.000	-	5.36
6	6.582	6.832	6.000	6.000	-	6.51
7	7.000	7.000	8.094	8.094	-	7.72
8	8.821	9.488	9.488	9.488	-	9.32
9	9.000	9.000	10.488	10.488	-	9.95
10	10.000	10.000	11.914	11.914	-	11.18
11	-	-	-	-	-	-
12	-	-	-	-	-	-
13	-	-	-	-	-	-
14	-	-	-	-	-	-
15	-	-	-	-	-	-

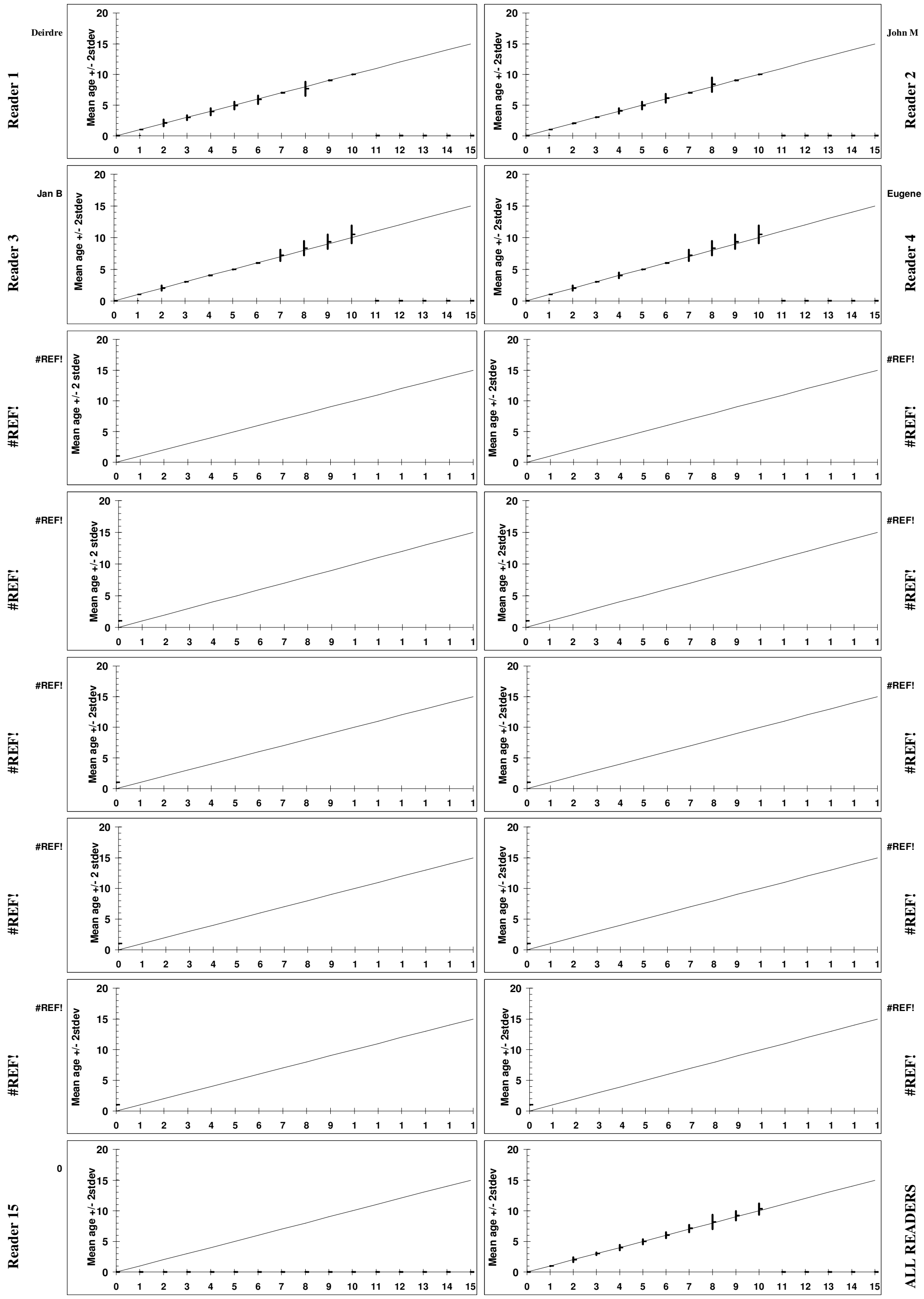
MEAN AGE -2STDEV

MODAL age	Deirdre Reader 1	John M Reader 2	Jan B Reader 3	Eugene Reader 4	0 Reader 15	ALL
0	-	-	-	-	-	-
1	-	-	-	-	-	1.000
2	1.547	2.000	1.658	1.658	-	1.663
3	2.586	3.000	3.000	3.000	-	2.802
4	3.321	3.619	4.000	3.619	-	3.571
5	4.339	4.339	5.000	5.000	-	4.554
6	5.168	5.418	6.000	6.000	-	5.492
7	7.000	7.000	6.306	6.306	-	6.484
8	6.512	7.179	7.179	7.179	-	7.012
9	9.000	9.000	8.179	8.179	-	8.388
10	10.000	10.000	9.086	9.086	-	9.324
11	-	-	-	-	-	-
12	-	-	-	-	-	-
13	-	-	-	-	-	-
14	-	-	-	-	-	-
15	-	-	-	-	-	-

Table 7 Agreed collection Criterion 80% agreement	
MODAL AGE	**n**
0	**0**
1	**1**
2	**25**
3	**27**
4	**19**
5	**10**
6	**6**
7	**4**
8	**1**
9	**2**
10	**1**
11	**0**
12	**0**
13	**0**
14	**0**
15	**0**
16	**0**
17	**0**
18	**0**
19	**0**
20	**0**
	96

Herring Otolith SET sample 4984,4986 2003

Figure 1 In the age bias plots below the mean age recorded +/- 2stdev of each age reader and all readers combined are plotted against the MODAL age. The estimated mean age corresponds to MODAL age, if the estimated mean age is on the 1:1 equilibrium line (solid line). RELATIVE bias is the age difference between estimated mean age and MODAL age.



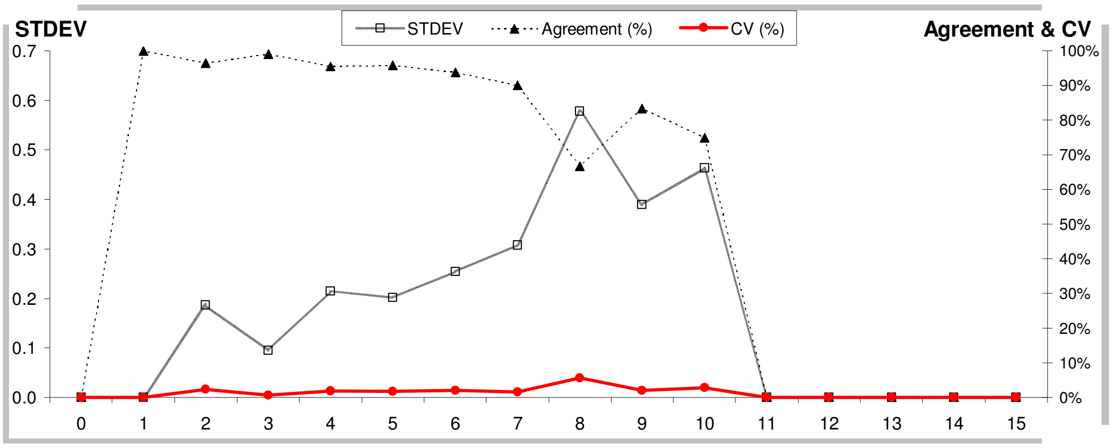


Figure 2 The coefficient of variation (CV%), percent agreement and the standard deviation (STDEV) are plotted against MODAL age. CV is much less age dependent than the standard deviation (STDEV) and the percent agreement. CV is therefore a better index for the precision in age reading. Problems in age reading are indicated by relatively high CV's at age.

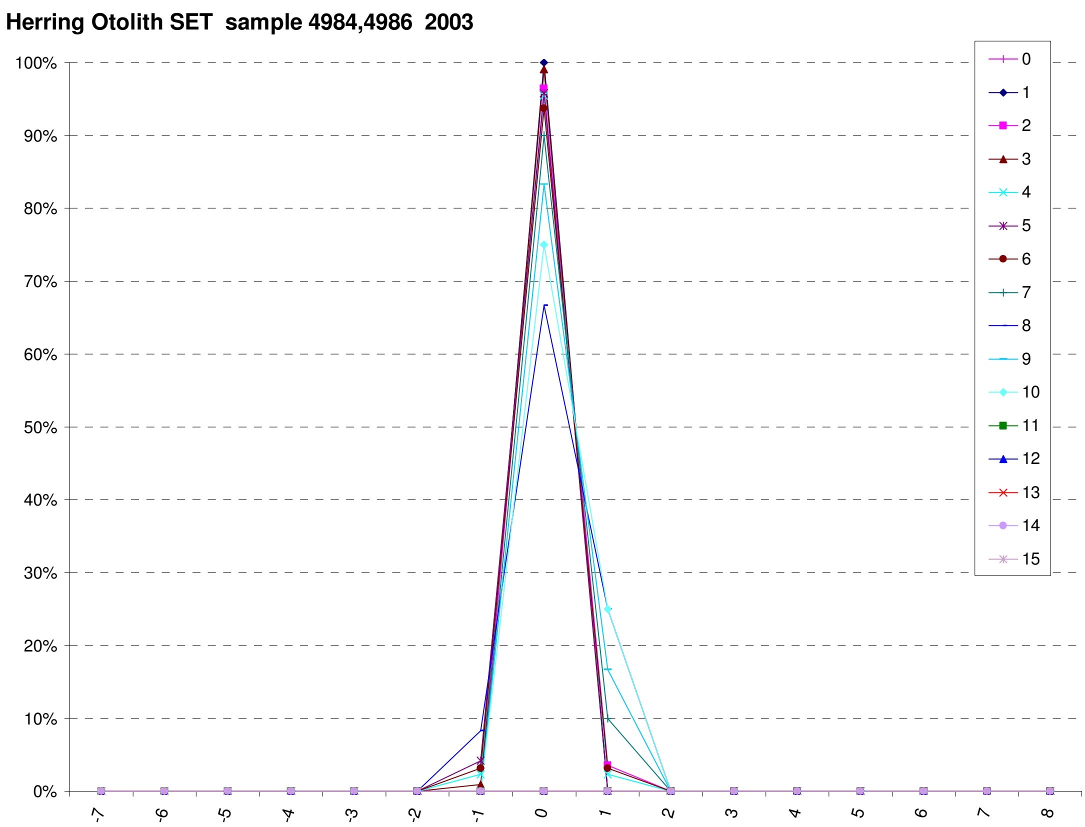


Figure 3 The distribution of the age reading errors in percentage by MODAL age as observed from the whole group of age readers in an age reading comparison to MODAL age. The achieved precision in age reading by MODAL age group is shown by the spread of the age readings errors. There appears to be no RELATIVE bias, if the age reading errors are normally distributed. The distributions are skewed, if RELATIVE bias occurs.

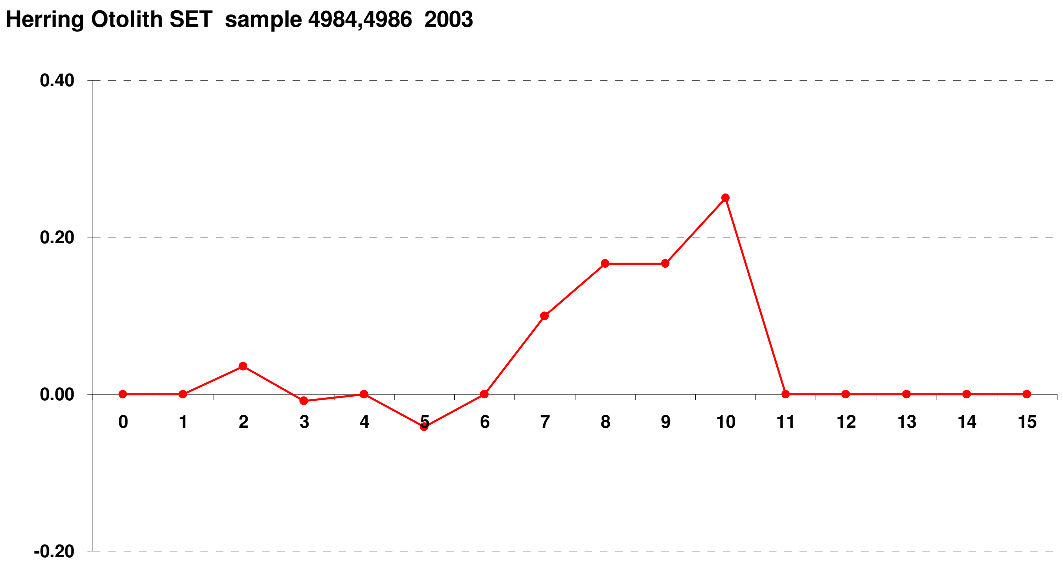


Figure 4	The RELATIVE bias by MODAL age as estimated by all age readers combined.

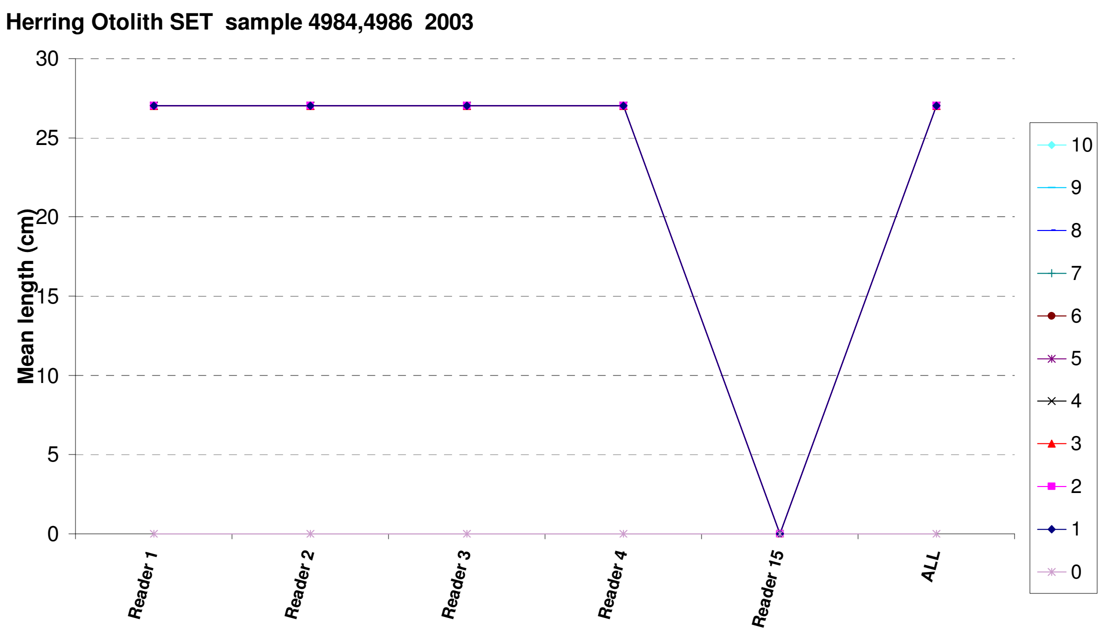


Figure 5	The mean length at age as estimated by each age reader.